A Novel Competency-Based Ontology for Enterprise Knowledge Modeling

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ABSTRACT

Enterprise competency refers to knowledge that describes the skills and abilities possessed by a particular enterprise. This dissertation proposes a new framework for intra-enterprise competency modelling. First, formal definitions of enterprise competency and related aspects (i.e. resource, activity, and knowledge) are presented. Second, conceptual sub-categories (i.e. capability, cross-functional co-ordination, and cross-functional integration) are discussed for the purposes of capability and competency modelling. The framework is illustrated by developing a competency knowledgebase for a bicycle plant with two sectors. Furthermore, the developed competency-based ontology is employed as knowledgebase for developing an RFID-enabled intelligent distributed manufacturing control system. The competency knowledgebase provides information important to decision-making, and can act as an indicator for an enterprise's willingness to engage in robust collaboration.

Keywords: Enterprise modelling, enterprise architecture, knowledge management, competency modelling, capability modelling.

ÖZ

Kurumsal yetkinlik belirli bir işletme tarafından sahip beceri ve yeteneklerini açıklar bilgi anlamına gelir. Bu tez içi kurumsal yetkinlik modelleme için yeni bir çerçeve önermektedir. İlk olarak, kurumsal yetkinlik ve ilgili yönleri (yani, kaynak, etkinlik ve bilgisi) resmi tanımları sunulmaktadır. İkincisi, kavramsal alt kategoriler (yani yeteneği, çapraz fonksiyonlu koordinasyon ve çapraz fonksiyonel entegrasyon) kapasitesi ve yetkinlik modelleme amacıyla tartışılmıştır. Bu çerçeve, iki sektör ile bir bisiklet bitki için bir bilgi bankası yetkinlik geliştirerek görüntülenmiştir. Ayrıca, geliştirilen yetkinlik bazlı ontolojisi bir RFID özellikli akıllı dağıtılmış üretim kontrol sistemi geliştirmek için bilgi bankası olarak kullanılır.Yetkinlik bilgi bankası karar verme önemli bilgiler sağlar ve sağlam işbirliği yapmaya bir işletmenin istekli bir göstergesi olarak hareket edebilir.

Anahtar Kelimeler: Kurumsal modelleme, kurumsal mimari, bilgi yönetimi, yetkinlik modelleme, modelleme yeteneği.

To my family

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The first part of this study took place when I was employed as a research assistant at the Department of Mechanical Engineering, EMU for five years from 2007 to 2012. Then, I was supported by same department as a lecturer. I would like to have a special thanks to the chair at department of Mechanical Engineering, Prof. Dr. Ugur Atikol. Also, I would like to thank my faculty member at the same department for a friendly atmosphere.

I have some "friends" who have been annoying me by asking about the status of my thesis work on all occasions during the last years. I am not quite sure if I should thank them or not!

Last, but not least, I have to thank my brother Ali Vatankhah Barenji for kindly scientific supports and always novel ideas. I must thank my family for their unfailing encouragement, love, support, and patience. They have supported me all the time, and their primary concern is always my well being. They always encouraged me to pursue higher education.

Reza Vatankhah Barenji

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Chapter 1

INTRODUCTION

1.1 The Problem statement

In recent years, a number of enterprise engineering researchers have outlined the theoretical case for enterprise knowledge management. It is claimed that with product life-cycles shortening and technologies becoming increasingly imitable, enterprise knowledge emerges as a major source of competitive advantage by virtue of its inimitability and immobility. Enterprise engineering is an approach for easy-to-understand definitions of the enterprise's business entities and relationships; processes and planning; [1] organisational structure; (d)[2] market details and products/services; (e) and high-level planning and preferences[3-5]. The artificial intelligence and enterprise modelling communities have developed important enterprise models and/or ontologies, including: the Toronto Virtual Enterprise (TOVE), the Open Information Model (OIM), Computer Integrated Manufacturing Open System Architecture (CIMOSA), IDEON, Business Process Modelling Language (BPML), and Collaborative Network Organisation (CNO).

Meanwhile, the global market encourages organizations to have a clear understanding of their area of expertise in order to maintain a competitive advantage. In addition to the enterprise model, it is important to capture and manage the knowledge and skills of enterprises' internal competencies [6]. Some professionals and researchers refer to these areas of organizational expertise as competency. Enterprise Competency is a crucial factor in business scenarios, in that it provides a more nuanced description of an enterprise's[1, 7] or individual's[8] profile. Such a profile demonstrates the knowledge, skills, experience, and attributes necessary to effectively implement a defined function [8] That competency is an essential component of enterprise engineering, acting as a new means to consider knowledge capitalization[9], associated with a new vision of performance[10, 11], as well as new forms of ontology[12]. First, the understanding and auditing of competencies acquired, required, and desired by a company and second, representing them in a structured manner, are beneficial steps for enhancing the company's performance [1, 13, 14].

There exist several definitions for competency, notable among them. In early 1990's [15]described core competences as the "collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams of technologies", Boucher et, al, 2001[16] defines competency as "the interaction between three components: the professional situations, the actors, and the resources" and, Mueller, 2006 [17] describes competency as "the smallest autonomous performance unit able to create value, be indivisible and able to exist independently Javidan, 1998[1]in his supplementary definition for core competency introduced, resource, capability and competency as three key paradigms which need clarification and definition in order to found an enterprise core competencies. He believes that, the first step in successfully identifying and exploiting an enterprise's core-competencies is creating a universal model for the competency, capability end organizational resources. Capability referred as; enterprise's ability to exploit its resources. For better exploitation of the resources, information about activates which are realizable at the resource and the knowledge about how these resource and processes can work together are useful and essential issues. ”. Minimizing risk and acquiring sufficient enterprise information while reducing costs and time-to-market are the main plans leading to storage, management, and maintenance of organizational competencies.

Competency model is an information and knowledge model that describes the skills and abilities of a particular organization. Organizations need comprehensive competency model for successful management of internal resources/activities and corresponding their inter-related activities[18]. For an organization to participate in Virtual Organization Breeding Environment (VBE) activities, prior submission of competency model is necessary [19]. On the other hand, competency models are essential tool for improving organizational core competency [20]. In small and medium size enterprises, the competency models can be developed from oral information while, in a more complex organization , the collection and modeling of competency by human actor is not any more effective [21]. In such cases, computer-based mechanisms are required. Available literature reviewed emphasizes competency model as a paradigm which depend on modeling purpose that varies from one model to another [22]. Furthermore, collection, analysis and management of competencies for modeling purpose are a complex task involving many aspects of manufacturing and business environment.

Despite the plausibility of these arguments, however, relatively few studies have provided empirical insights into how companies identify, represent, and manage ‘enterprise competency’ through the interplay between organizational context and information technology. Indeed, much of the existing literature is concerned with an ontological debate about the conceptual nature of competency and therefore tends to promote particular approaches as universal panaceas. More specifically, with the development of the field of ‘competency management’ there has been a massive outpouring of articles dealing with these issues from a prescriptive standpoint. Their relatively weak empirical base notwithstanding, many of these contributions confidently define enterprise competency as a kind of economic asset or commodity, or as a purely cognitive phenomenon. These theoretical arguments are difficult to relate to the actual experience of business organizations. We also know comparatively little about the actual organizational processes through which enterprise competency is valorized in competitive outcomes.

1.2 Objectives and Contributions

In an attempt to shed some light on the above-mentioned issues, the main objective of this dissertation is to examine the dynamics of successful competency modeling practices, and to consider the extent to which such practices can be generalized and adapted by others. Therefore, the overall effect of this theoretical approach is to bridge a gap between the abstract concepts that we employ to understand enterprise competency and the practical, context-dependent realities facing business organizations.

The main aims of this research thesis are: (a) understand capability and competency concepts (b) introduce an approach to store, manage, represent and maintenance capability and competency of an organization at different levels of abstraction (c) suggest some criteria for using competency as ontology for organization integration. The central research questions which are addressed in this research dissertation are as follow;

RQ1) How to model an organization with its existing competencies?
RQ2) What are the templates, procedures and methods to store, maintain and manage competency of an organization?

To answer the above research questions, the hypothesis prepared are as follows;

Hypothesis1) If we combine multi-phase modeling views with associated needed competencies then we can better understand product evolution, customization potential, and retrofitting needs.
Hypothesis2)If we combine competency model paradigm with co-innovation and involvement of local stakeholders then we can have a more effective life-cycle support for complex products, including customization, maintenance, and retrofitting.

1.3 Dissertation Organization

At the first step of this research contribution, based on existing well-known competency models, a conceptual competency modeling framework for organizational competency is developed. The proposed competency modeming framework is act as road maps for enterprise competency modeling propose. This step will be presented in chapter 3. For the second step, using an example, a capability model of a shop is developed. This capability model is used for decision making process at the shop. The example used for this step is Flexible Manufacturing Systems

(FMS) Lab of the Eastern Mediterranean University. The detail of this step is presented at chapter 4. At the third step, using a real example, the enterprise competency model is proposed, developed and under implementation. The case study was a bicycle manufacturing plant. This step is presented at chapter 5 of this dissertation. For the last step of this research contribution, the developed competency-based enterprise knowledgebase is employed as an anthology for developing an RFID-enabled distributed manufacturing control system. The detail of this step is fundable at chapter 6. Chapter 7 concludes the dissertation and suggests some future works.

The results of this dissertation are published [2, 23-26](or submitted for publication) in a number of journals, books and conference proceedings. These publications are listed below for different chapters.

Chapter 3

1. Barenji, R.V, Hashemipour, M., & Guerra-Zubiaga, D. (2012). Toward a framework for intra-enterprise competency modeling . 2nd IEEE International Conference on Advanced in Computational Tools for Engineering Applications (ACTEA)(pp.278-282).
2. Barenji, R. V., Hashemipour, M., & Guerra-Zubiaga, D. A. (2013). Toward a Modeling Framework for Organizational Competency. In Technological Innovation for the Internet of Things (pp. 142-151). Springer Berlin Heidelberg.
3. Barenji, R. V., Hashemipour, M. Developing competency-assisted collaborative promotion framework in higher education in developing countries and beyond, Submitted to European journal of education

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Chapter 4

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6. Barenji, R. V., Hashemipour, M. A Capability-Based Decision Support System for a Manufacturing facility. Submitted to IEEE Transaction on Industry Applications

Chapter 5

7. Barenji, R. V., Hashemipour, M. Enterprise Competency Modeling -A Case Study. In Technological Innovation for the Collective Awareness Systems. Springer Berlin Heidelberg. (in press)
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9. Barenji, R.V, Hashemipour, M., & Guerra-Zubiaga, D. A Framework For Modeling Enterprise Competencies: From Theory To Practice In Enterprise Architecture, revised (7 Nov ,2013): International Journal of Computer Integrated Manufacturing

Chapter 6

10. Barenji, A. V., Barenji, R. V., Hashemipour, M & Sefidgari, B. L. (2013, August). An RFID-enabled distributed control and monitoring system for a manufacturing system. In Innovative Computing Technology (INTECH), 2013 Third International Conference on (pp. 498-503). IEEE.

11. Barenji, A. V., Barenji, R. V., Hashemipour, M (2013). Structural Modeling of a RFID-enabled Reconfigurable Architecture for a Flexible Manufacturing System. ITG-Fachbericht-IEEE Smart SysTech 2013.
12. Barenji, R. V., Barenji, A. V., Hashemipour, M. A Multi-Agent Rfid-Enabled Distributed Control System For A Flexible Manufacturing Shop, The International Journal of Advanced Manufacturing Technology, Springer (In press)
13. Barenji, R. V., Barenji, A. V., Hashemipour, M. An Architecture For Structural Modelling of an RFID-Enabled Intelligent Distributed Control System at a Manufacturing Facility, revised (27 Dec ,2013): International Journal Distributed Sensor Networks

Chapter 2

A STATE-OF-THE-ART: ENTERPRISE COMPETENCY-CONCEPT AND TRENDS

2.1 Overview

In this section, for discovering the competency associated concepts, the most cited competency related concepts as well as models are taken in to consideration. To begin with, the most relevant well known definitions and exist models for capability on both organizational and computer science literatures are reviewed. Further then, exists definition for competency and modeling perspectives are highlighted.

2.2 Manufacturing Capability

Capabilities refer to the company's ability to use its resources. In that, capability is a chain of business processes and routines which manage the interaction between its resources. Javidan 1998, [1] proposed additional definition, where he extends the capability notion using a hierarchical definition. The primary level was resources ("building blocks of enterprise"), the second level in the hierarchy was capability which consists of a "series of activities and strategies that control /manage the relations among its resources". Wherefore Javidan believed and comprehended that the capabilities of an organization can be categorized based on organizational functionality. Functionalization of the capabilities denotes the process of grouping capabilities into departmental capabilities. A good illustration is for instance; R&D, design and prototyping, production, marketing and after sales. These are some of the departments engaged in a manufacturing organization. Conceptually and empirically, applicability of Javidan's capability definition motivates many of the researchers with the authors included in this contribution for employing this method in their work.

Manufacturing capability can be described as a set of information embedded by all available resources and corresponding processes that could be performed by those resources, as well as the knowledge about how these resources and processes can be effectively, efficiently and economically used [27].

The manufacturing capability definition includes three broad features, resources, processes and knowledge, where:

- Resources: means building block of capabilities. Resources can be categorized, into three groups: physical resources such as plant, equipment; human resources such as manpower, management team, and training, experience, and organization resources such as Brand name. Some resources are tangible such as equipment and others intangible such as financial resources[1].

- Activities: according to [28] From a bottom-up perspective, activities carried out by a company are usually organized in "clusters" of inter-related activities called processes (business processes). The composition of each process is designed in order to achieve a (partial) specific goal". Alternatively from a top-down view, a process can be decomposed into a hierarchy of sub-processes and activities.

- Strategies (Knowledge): the strategies are useful decisions made on the organization of the resources and processes (an example is constraint imposed on the usefulness of a certain type of resources and/or processes). In the capability model, knowledge represents the manner in which the resources and activities are being structured and adapted to support the realization of the function in order to achieve the objectives of a department[29, 30].

2.3 Enterprise competency

Enterprise competency is an important paradigm for obtaining competitive advantages and leverage by using a 'know-how' approach [5]. It refers to the skills and abilities of an organisation needed to carry out certain tasks based on knowledge and experience of its methods and resources [31]. Understanding and sharing competencies improves firm performance in a number of respects [10, 32, 33]: (a) attracting, retaining and improving the best available resources for creating and realising continuous value creation and distribution; (b) publishing the competency of one's own firm in the market and identifying potential opportunities for cooperation; (c) increasing awareness about one's own current capabilities as well as understanding competencies that other companies can offer (thereby allowing for the identification of areas for future development); and (d) initiating or mediating new partnerships.

In earlier definitions and models, competency primarily refers to capabilities. As a result, 'competency' and 'capability' are often considered synonymous. For example, Gallon and Stillman (1995) [34] define competency as 'aggregation of capabilities, where synergy that is created has sustainable value and broad applicability'. Javidan [1](1998) proposed a different definition to supplement the conceptualisation proposed by Gallon and Stillman. While the traditional definition did not account for an enterprise's multi-functionality, the definition proposed by Javidan is based on an enterprise's functions (e.g. manufacturing sector, marketing sector). He conceptually distinguished the associated concepts in a ‘competencies hierarchy’. The hierarchy treats resources as the foundation. Capabilities are modelled such that they are built upon resources. Finally, competencies are built upon resources and capabilities.

Attempts at modelling enterprise competency are typically carried out within two distinct research communities[35]: (a) managerial sciences and industrial engineering and (b) information/knowledge managerial sciences. The focus on intra-enterprise competency modelling gives rise to the question of how internal competencies of an enterprise can be identified, captured, and modelled in a manner identifiable by human and machine, allowing an enterprise to successfully engage global competition and endure fluctuating market conditions. There has been a substantial amount of research within managerial sciences and industrial engineering [19, 36, 37] related to enterprise competency modelling and management, but few of these efforts have considered enterprise competency from an enterprise information technology perspective [35]. Instead, research within these domains has largely focused on manufacturing capabilities. As a starting point for this, Molina and Bell,1999 [38] propose a model for manufacturing capability to support concurrent engineering. The authors introduced manufacturing capability as combination of processes, resources, and strategies in a specific workflow. Further, they believe that manufacturing capability models can be used to support concurrent engineering. A number of researchers have applied Molina and Bell’s manufacturing capability model to create knowledge base. Most notably Zhao et al.(1999) [39] proposed a model to support virtual enterprises. Further, , developed a manufacturing knowledge model to facilitate decision-making. Further research work on manufacturing capability, and decision support systems focuses on contexts can be found at [40]. To summarise, (1) resource, activity, and manufacturing strategy are three fundamental components for capability modelling, (2) extant research has mapped manufacturing strategy as knowledge related to processes and resources (knowledge), and (3) capabilities are the building blocks of the enterprise's competencies (Figure 1).

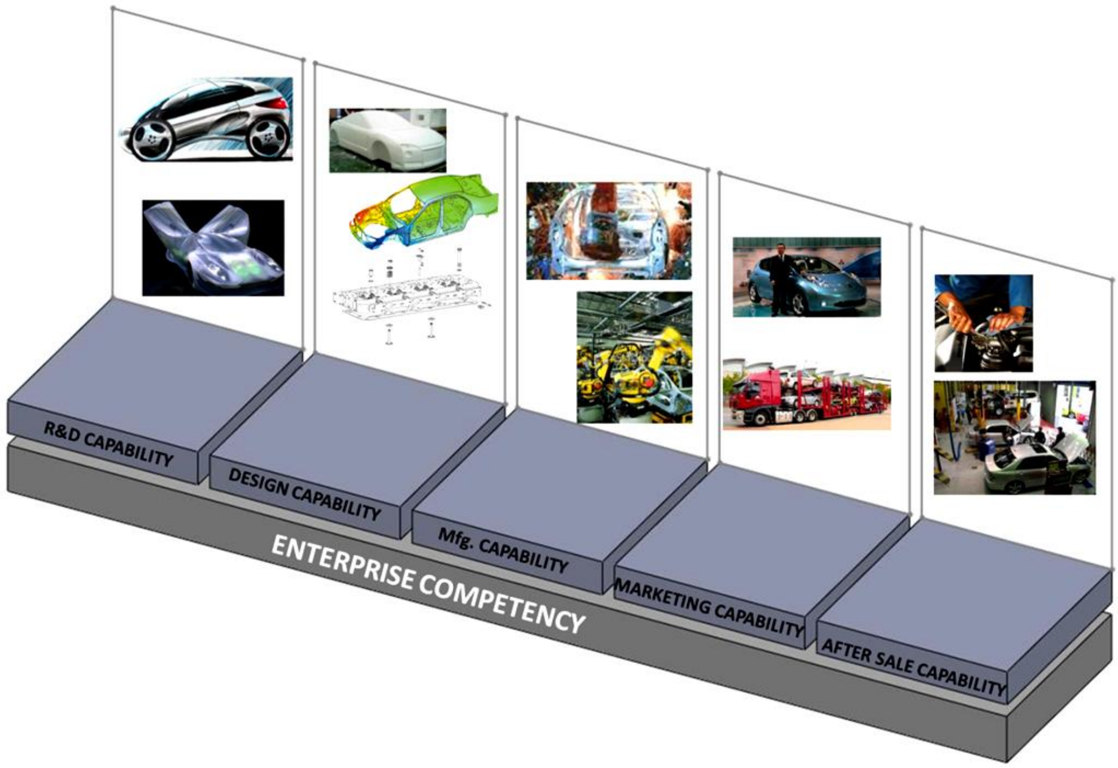


Figure 1Elements of the intra-enterprise competency system

In the context of a complex paradigm like competency, modelling is fundamental for understanding, managing, simulating, and predicting the attribute of the paradigm, and especially for software development [29]. Figure 1 illustrates some of the important questions that a modeller may pose when attempting to model competency at the intra-enterprise level. Certainly, many other relevant questions may be asked in relation to competency modelling.

Figure 2-Examples of modeling purposes

There are several models for enterprise competency within the research communities outlined above. These models, though related to each other, have different areas of application. Therefore, the models themselves differ. For the purpose of explication.

Table 1-an attempt to map current competency models applicable to competency modeling framework

Intra-enterprise (managerial sciences)		
Reference	Research contribution	Modeling area
(Prahalad & Hamel, 1990) [15]	Core competency notation	Organization competency, definition at concept level
(Javidan, 1998) [1] (Ljungquist, 2007) [7]	Core competency hierarchy	Organization competency, concept model
(Gilgeous & Parveen, 2001) [41]	"To assist in core competence management an enabling core competence lens model was presented together with a framework for core competence maintenance"	Enterprise competency, organization competency, at detail level
(Ran Bhamra , Samir Dani , & Tracy, 2010) [42]	"Investigating the existence and nature of core competency concepts within a section of UK SME manufacturing organizations"	Organization competency, concept and basic level
Intra- enterprise(Information/ knowledge managerial sciences)		
(Zhang & Lado, 2001) [43]	Analyze IS role in raising organizational competencies and prompting the cross-functional	organizational competency at concept level

	integration necessary to achieve scale, scope, and learning curve economies for an enterprise.	
(Walsh & Linton, 2001) [44]	Develop a framework for enterprise competency modeling	Enterprise competency, organization competency at concept level
(Harzallah & Vernadat, 2002) [8]	Competency modeling and management	Enterprise competency, and individual competency at basic level
Inter-enterprise(managerial sciences)		
((HR-XML, 2001) [45]	Partner selection	Sharing competency, at organizational level
Inter-enterprise(Information/ knowledge managerial sciences)		
(HR-XML, 2001)[45]	Providing trading partners standardized and practical means to exchange information about competencies within a variety of business contexts	Sharing competency, at organizational level
Network(managerial sciences)		
(Molina & Flores, 1999) [38]	Core competencies in the manufacturing clusters	Organization competency at concept level
Network(information/ knowledge Managerial sciences)		
(Mueller, 2006) [17]	Planning of production system for the competency cell-based networks	Enterprise competency, basic and detail level
(Paszkiewicza & Picarda, 2011) [46]	Partner selection in Virtual Organization Breeding Environments	Enterprise competency modeling at detail level
(Cheikhrouhou, Tawi, & Choudhary, 2012) [47]	"extension of the competence-oriented modeling approach through a unified enterprise competence modeling language (UECML	Enterprise competency, modeling at basic level and detail level
(Ermilova, Ekaterina; Afsarmanesh, Hamideh, 2010) [19]	Competency modeling for collaborative network organizations	Organization competency, basic and detail level

A summary of our main observations are as follow:

- Similar to organization management theory, which hierarchically subdivides organization into four tiers; shop, enterprise, organization and network, the competency models depending on the organizational level differ from one tier to another. Shops as an organization just comprises of capability not competency so there is no competency model for shop level. For enterprise level, there exist three different sets of competencies models namely individual, enterprise and collaboration-oriented. For organization level the models refers to core competencies of the organization and for network level the models deals with sets of competencies which each organization shared within the network.

- The reviewing on competency model literatures emphasis that competency model is a research context from both organizational management and computer science points of view meanwhile, this context is significant at intra-organization, inter-organization and network levels.
- An important task during competency modeling is to provide an abstract representation of the model on which the model is to be used. The structure and level of details depending on the further intentions of using this specific model is a three level architecture: concept level, basic level and detail level.

Chapter3

A MODELING FRAMEWORK FOR ENTERPRISE COMPETENCY

3.1 Overview

Competency modeling framework serves as a; (a) very important basis for the explanation of a generic competency modeling approach, (b) base element in the consolidation of existing knowledge in this area, (c) tool for model developers on selecting appropriate competency models, and (d) basis for competency modeling. This chapter uses literature review approach to propose a modeling framework for organizational competency. The proposed modeling framework has been developed based on the most relevant well known competency models. The research suggests that organizational competency can be categorized into three groups; individual competency, enterprise competency and collaboration-oriented competency. For modeling each of these groups, it is essential that the modeling process have to be aligned with model developer purpose (Modeling perspective), thus the model developing process will be based on the same segmentation model. Furthermore, competencies have to be model at different levels of abstraction (modeling intent).

3.2 Introduction

"A modeling framework can be seen as an envelope that includes a number of models, collections of templates, procedures and methods, rules, and even tools" [48].When attempting to establish a modeling framework, it is important to consider the potential inputs and partial contributions from previous related works for proper system requirements [16]. This chapter uses literature review approach for the requirement analysis phase. In this way, we strived to harness the advantages offered by a number of well-known competency models introduced by other initiatives, and attempted to eliminate some of the common pitfalls which theoretically or empirically, model developers face while establishing a model.

Clearly, this attempt does not argue about the relevance and appropriateness of previous well known models, for the purpose of organizational competency modeling. Rather it argues and represents (i.e. through identifying more elements) that more needs to be done for the purpose of proper organizational competency modeling. As such, instead of starting from scratch to identify the main perspectives and required elements for competency modeling, we have tried as much as possible to reuse some already defined concepts that are more familiar to the users of model, model developers and researchers in this area.

Competency modeling framework is an important basis towards the development of competency models. Competency modeling framework intends to help model developers to identify what kinds of competency models have to be created for successful decision making [49]. What have not been published in competency modeling context, however, are, a comprehensive modeling framework for organizational competencies and, a generic capability and competency model which can be used by researchers and decision makers. The purpose of this chapter is to develop a modeling framework for organizational competency. The modeling framework has been developed using a literature reviewed approach. In essence, the proposed modeling framework has been developed based on the literature review and evaluated with the aid of most relevant well known competency models.

3.3 Research methodology

To effectively conduct the proposed research investigation and develop a competency modeling framework (CMF) a research methodology developed as below. The proposed methodology illustrates the CMF configuration processes from requirements analysis (literature review approach) to CMF development. Figure 3 represents the methodology. In the requirements analysis phase, primary 86 related journal papers were extracted both from computer science and organizational management data bases. After elimination of the papers with less novelty and or fewer citations, 46 papers have been used in the final requirement analysis phase. These requirements are then utilized for generalization phase which proposed the modeling framework perspectives. Ultimately, the generalized perspectives are employed to propose a competency modeling framework.

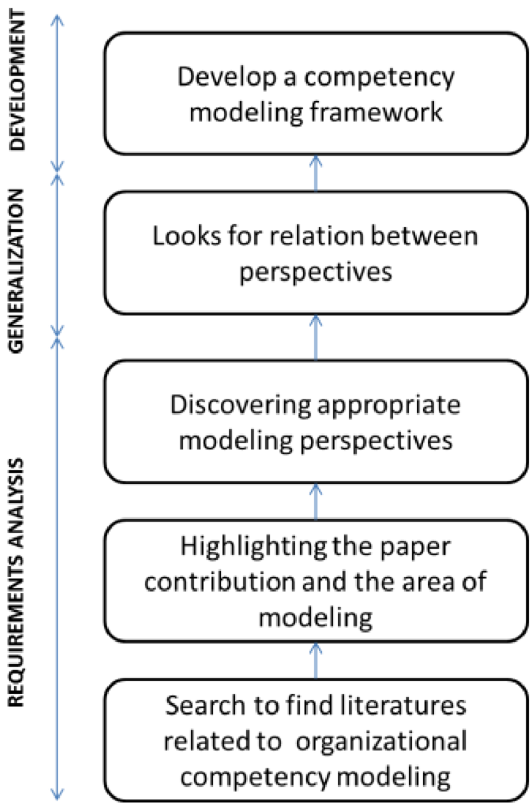


Figure 3-Competency modeling framework Research Methodology

3.4 Toward a comprehensive competency modeling framework

3.4.1 Competency inherent characteristic

Competencies within an organization mainly can be categories in three groups, individual competency; enterprise competency and collaboration-oriented competency. The incorporation of the individual competency, enterprise's competencies and collaboration-oriented competency were referred as organizational competency [50] (see figure 3 from bottom to top), while a portion of the organizational competency which an enterprise decides to share within a network is entitled as sharing competency.

According to the U.S. Department of Labor, employment and training administration, individual competency, described as: [51] "the ability or capability of the individuals to apply the required set of skills, abilities and related knowledge to perform certain task successfully in a defined work setting". As a result of the ETA definition, Individual competencies denotes from the individuals of the organization. The second class of competencies is enterprise's competencies which refer to a set of competencies that constitute from enterprise facilities beside manufacturing and business knowledge [52]. This class of competencies captures information related to enterprise activists and resources and knowledge correlated to activity and resources [53].The third class of competency is collaboration-oriented competency, which is the organizations ability to cooperate and collaborate by working together towards achievement of a common goal [50]. Interaction and communication are highlighted as establishing the basis for shared understanding, which in turn is considered the basis for the creation of collaborative-oriented competency in a network [53].

Based on most recent categorization, the first defined dimension for competency modeling framework focuses on capturing competency inherent characteristics is represented by the vertical axis, labeled as “competency inherent characteristic”. This perspective further includes three subspaces that comprehensively cover all the inherent characteristics of the organizational competency. The individual competencies of the organization (labeled “Individual competencies”); the enterprise competencies characteristics (labeled “Enterprise competencies competencies”), and collaboration-oriented competencies (labeled” Collective competencies”).

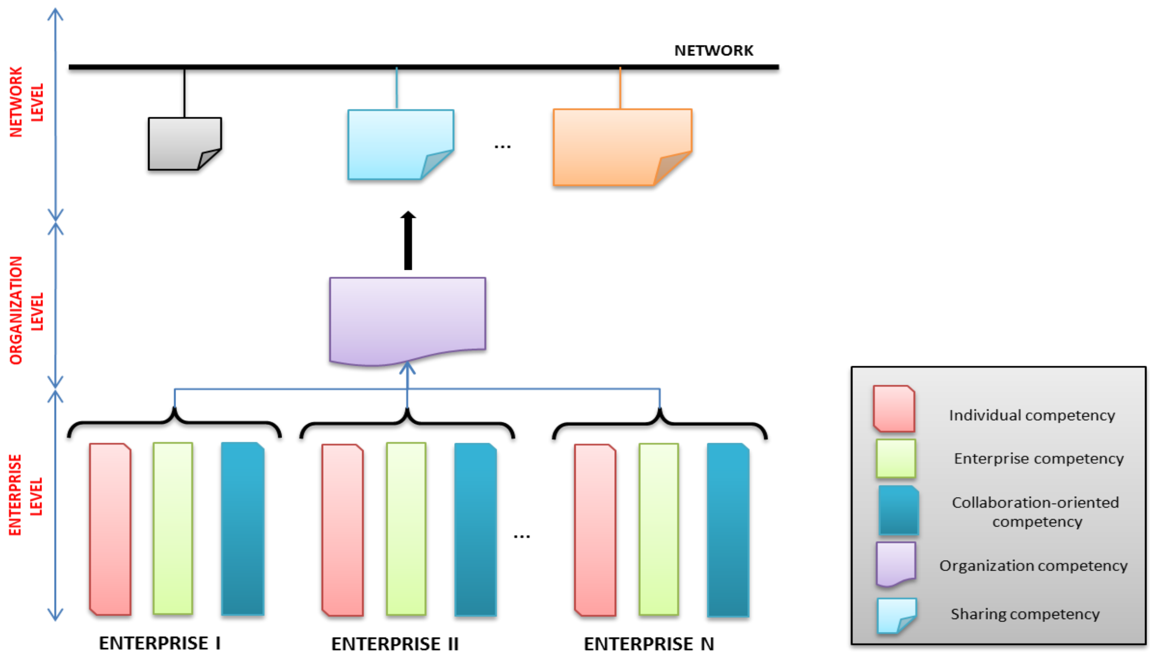


Figure 4- Competency inherent characteristic

3.4.2 Modeling viewpoint

From the system theory points of view, competency is complex entities operating in a variety of environments having different purposes and internal/external manufacturing and business processes [54].The existing competency models developed on two spaces namely; (a) managerial sciences and industrial engineering and, (b) information/knowledge managerial sciences (depicted in figure 5). These spaces although are related to each other, have different position in regards to the competency model, and thus the models defines in these views also differ.

On the other hand, the operating of competency models may occur at internal and/or external manufacturing business processes of an enterprise. [55] divide their researches on competency into intra-organization, inter-organization and network levels. Intra-organization oriented studies deal with the competencies within an organization. When the competencies are not bound to a single organization we talk of inter- organization level. Competencies for the static forms of cooperation among organizations that go beyond their boundaries could be subsumed under the term of supplier networks. Network level studies, consider, competencies need for creation of Virtual Enterprises as a network organization as well as competency as a tool for improve the VO performance.

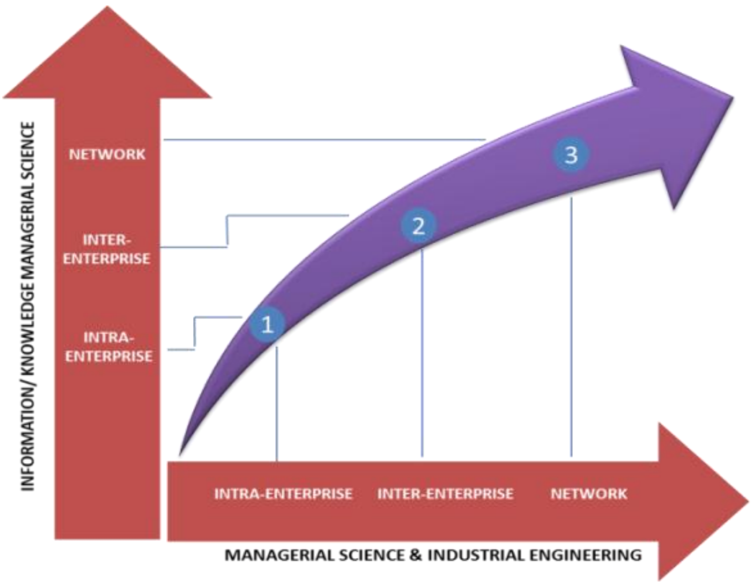


Figure 5-modeling perspectives for competency modeling

The modeling perspective capture the modeling requirements and the diversity for internal and external manufacturing and business processes and for different purposes is be represented by the vertical axis, labeled as "modeling perspective".

The second defined modeling perspective addresses the competency modeling viewpoints as represented by horizontal axis on competency modeling framework. These viewpoints include "managerial science and industrial engineering" and "information/knowledge managerial sciences". Accordingly, competency at both viewpoints includes a variety of requirements and these requirements can be categorized into three different groups: intra- organization, competences within an organization; inter- organization, competencies beyond the boundary of the organization but for cooperation and network, competencies for the collaboration networks.

3.4.3 Modeling intents

The contemporary organizational theories distinguish three hierarchical levels for organization management: organizational level, infrastructural level, and content level [56]. On the basis of such hierarchical system, it is possible to define three adequate levels in competency modeling processes. The third defined perspective is related to the different intents for the modeling of competency features, will be represented by the diagonal axis, and labeled as "modeling intents". This perspective addresses the three possible modeling stages for competency elements; from the organizational level, to the infrastructure level (e.g. using a specific modeling approach or theory), and finally to the content level.

Following the research practices in modeling, the three layers below are considered as follows:

- Organizational level: includes the most general concepts and related relationships, that is common to all competencies at the highest level, independent of the application domain.
- Infrastructure level: an intermediate level that includes more detailed models, focused on different classes of competencies.
- Content level: that represents models of concrete competencies.

3.5 Proposed modeling frameworks

In this section, the proposed modeling framework for organizational competency is presented. To begin with, the general modeling framework is given. For the sake of consistency, the authors have named the suggested modeling framework, Comprehensive Organizational Competency Modeling Framework (COCMF). Figure 5 shows the developed modeling framework for the competencies. It can be argued that organizational competency models can be encapsulated into a process of three dimensions: Competency inherent characteristic, Modeling perspective and Modeling intent. COCMF explore the granularity of the competency with the purpose to systemize competency models which will be applicable for the transformation of an organization into a knowledge-based system [57], and its alignment with business goals and the range of other business management functions [56].

In this matrix, for the three subspaces of the individual competency, enterprise competency and collaboration-oriented competencies which forms the "competency inherent characteristic" dimension; their respective dimensions are depicted as different columns. Similarly, for the modeling perspective, each perspective is depicted as one row. The Modeling Intent constitutes the third dimension of the matrix, with its three respective subspaces of organizational level, infrastructure level and content level.

Each of 54 items within the COCMF possesses its own semantics and identifies the definite component of competency model, which integrates three dimensions: modeling perspective, inherent characteristic and modeling intents at the same level of elaboration. E. g., item 111 represents the integration of a competency model concerning three aspects of individual competency, intra-enterprise at managerial science points of view that are used at the organizational level. There are three, two-dimensional subspaces of the COCMF, namely, E1, E2 and E3.

The subspace E1 “modeling perspective- competency inherent characteristic” defines models that are used to support modeling perspective at a definite inherent characteristic (individual, enterprise and collaboration oriented). The subspace E2 “modeling perspective-modeling intents” describes modeling perspectives and their interactions with the modeling intents. The subspace E3 “inherent characterizes-modeling intents” characterizes the competency in the way it is used at each level of competency modeling.

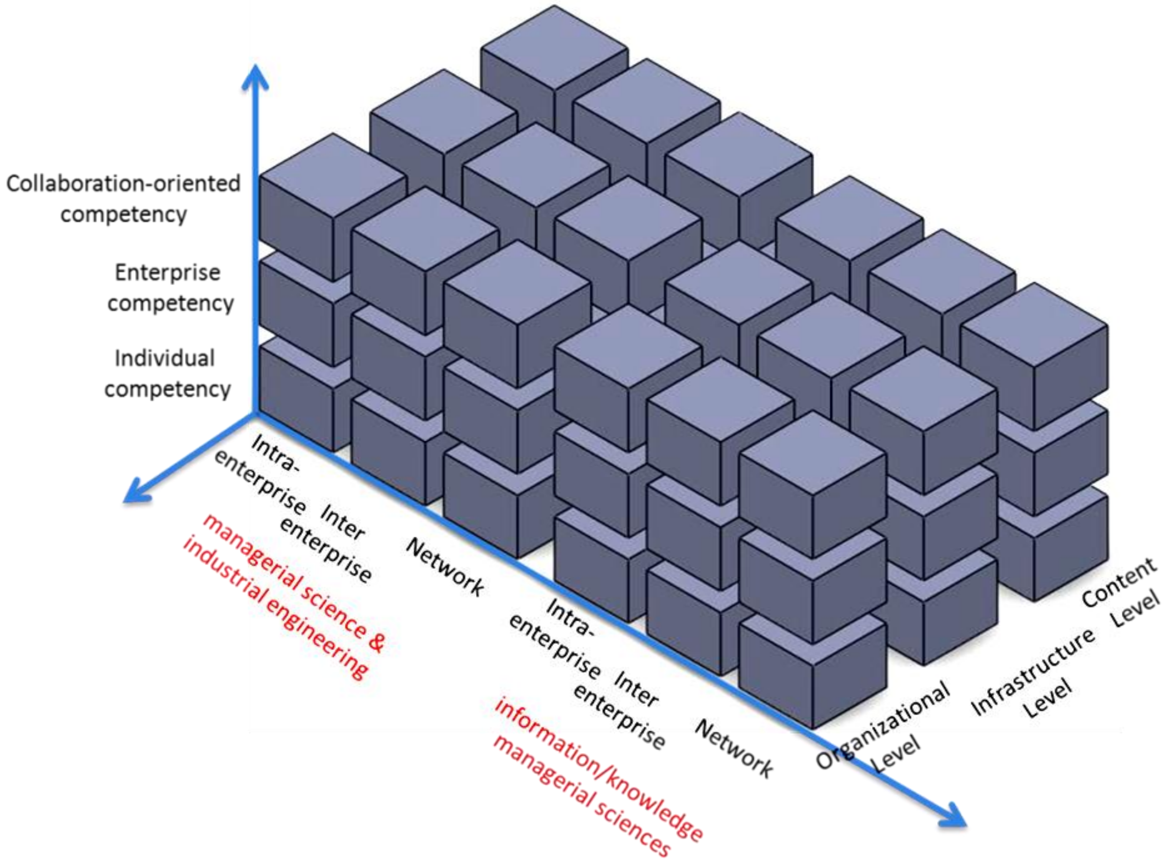


Figure 6-A modeling framework for enterprise competency

Our result of this study shows that although several related previous works have provided valuable contributions to the understanding of several aspects of this area, they are somewhat limited, when a more holistic modeling is pursued. This research suggests that organizational competency can be categorized into three groups, namely individual competency, enterprise competency and collaboration-oriented competency. For modeling each of these groups of competencies, it is essential that the modeling process have to be aligned with model developer purpose (Modeling perspective), so they exchange information, and operate based on the same segmentation model. Furthermore, competency have be model at different levels of abstraction (modeling intent).The main benefit of a competency modeling framework is enhancing decision making process for model developers. The main research limitation was; since the research is explorative in nature, therefore empirical data from similar and other research settings should be gathered to reinforce the validity of the findings. The major practical limitation of the COCMF is that a generic competency modeling approach is still needed for organizational competency modeling.

Chapter 4

CAPABILITY MODELING: WHAT DOES IT MEANS IN PRACTICE?

4.1 Overview

To succeed, long term organizations must compete efficiently and out-perform their competitors in a dynamic environment. To survive in this competition, identification, classification and management of organizational capabilities are vital. The capability management is the ability to achieve and exploit high efficiency from the resources, activities and strategies. Due to the significant volume of capabilities which are typically involved in a manufacturing shop, experts and intelligent systems are required to readily store, manage and maintain not only intra-organizational capabilities, but also the capabilities which are originating from the inter-organizational contexts such as networks of organizations. This paper presents a methodology for developing a system to store, manage, and maintain intra-organizational capabilities for decision making processes on resources, processes and strategies for business opportunities. The proposed methodology is explored in an educational manufacturing cell.

4.2 Introduction

Capability referred as; enterprise's ability to exploit its resources. For better exploitation of the resources, information about activates which are realizable at the resource and the knowledge about how these resource and processes can work together are useful and essential issues.

Meanwhile, according to organizational management theory, resource, process and strategy are the three main building blocks for decision support systems which can be used in wide areas of applications such as, manufacturability analysis and process plan generation. Substantial improvements have been made on constructing decision support systems aiming on the resources allocation process as well as on strategy selection in the case of a new business opportunity for an organization or networks of organizations. The existing decisions support systems are found to be looking on resources and processes information separately [1]. These systems are not able to deal with all pertinent features (resource, process and strategy) at the same time and covering the organization as a whole.

The primary aim of this chapter is to present a methodology for developing a system to store, manage and maintain intra-organizational capabilities used to develop a decision support system focusing on resources allocation and their related processes accompanied with a strategy selection for a new business opportunity of an enterprise. The chapter explained in details the structural model of the manufacturing data storage system for Computer Integrated Manufacturing (CIM) laboratory of Eastern Mediterranean University (EMU CIM lab) that has been constructed based on previous introductory capability models [58]. Next, the Architecture entitled as Capability Analyses Tool (CAT) is designed, which is used for resources allocation and processes including strategy selection of a new business opportunity on the enterprise.

4.3 Capability-based decision support system for manufacturing shop

The focus on capability as a key concept for decisions making process was first promoted in the managerial scientific literature with qualitative approaches of proficiency management [45]. However, since then, other scientific fields have integrated this significant notion and quantitative approaches; proposing decision support systems that brought up on interesting results. A starting point for the integration of the concept of capability in the field of information and knowledge managerial science for decision making process has been proposed in [23], where the authors carried out a model for manufacturing capability to support concurrent engineering. In this project they introduced the concept of manufacturing facility as combination of processes and resources. Furthermore, manufacturing capability was seen as facilities and strategies in a specific work environment and they believed that manufacturing capability and facility models could act as an approach for decision making process on concurrent engineering context. The formalization of capability concepts covers different types of industrial decision processes, for instance [52] proposed an approach for employing a capability model to support virtual enterprises; [59] proposed an approach to utilize a capability model to support global manufacturing co-ordination decisions: [58] developed a manufacturing knowledgeable model to create knowledge and maintenance for decision-making. As a summary, manufacturing strategy is described as knowledge related to processes and resources (knowledge model). A facility model is defined as a manufacturing information model, and a capability model is illustrated as manufacturer of both information and knowledge models. Further research work on manufacturing capability and decision support systems focuses on contexts such as knowledge maintenance [39], knowledge sharing using ontologies and representing global supply chains [60]. The recent developments however do not provide application guidelines on how to develop a data storage system for storage, management and maintenance of a shop’s capabilities used on decision support systems.

4.4 Research Methodology

The research methodology of this paper is sub-divided into three parts; “Preliminary study, problem definition phase”, “Design and development phase”, lastly “implementation phase”. Amongst “Preliminary study and problem definition phase”, “Design and development phase” there exists a “Verification block”. The modeling approach for this methodology is based upon object-oriented analysis and design techniques. The Unified Modeling Language (UML) is employed as a graphical modeling language, which enables the system developers, analyzers and stockholders to design and view the object-oriented systems. UML proposes a way to pursue a system's architectural blueprints, using different diagrams like use case diagram, class diagram, activity diagram, sequence diagram. Figure 7 represents the methodology. At the “preliminary study and problem definition phase” resources and processes of the desired shop are described. Two samples of working scenario are presented in this phase for illustration and better visualization. The “Design and development phase” shows an “As Is” model that introduces the system at higher levels of communication. For this, the UML use case for the shop floor and the general manufacturing capability model is introduced. This phase deals with identification and classification of information related to resources, processes and corresponding knowledge. For modelling the shop’s processes and resources UML sequence, activity, object, component, and development diagrams are employed. Different types of manufacturing knowledge are summarized and illustrated for the shop floor. A UML class diagram for knowledge type is developed for the shop floor at this phase. The “Verification block” realizes the impregnate processes between the “Preliminary study problem definition phase”, and “Design and development phase”. In verification block extracted requirements of the system acts as a verification indicator. The UML models of the current system as well as UML models of the new system are transferred to XML files and compered with each other in order to found whether met the requirements.

A capability-based data storage system is developed in the “Implementation phase” and application architecture for the desired decision support system on the shop is proposed. The proposed methodology will be explained using the Computer Integrated Manufacturing (CIM) laboratory of Eastern Mediterranean University.

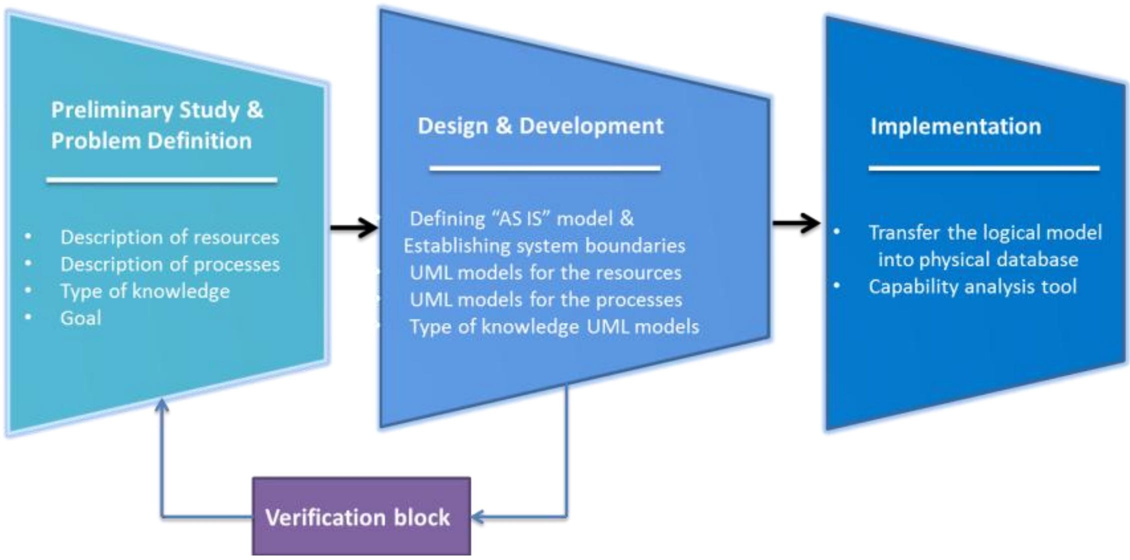


Figure 7-Research Methodology

4.5 Preliminary Study and Problem Definition Phase

The EMU-CIM laboratory was designed for education and research purposes. The laboratory consists of three stations: Station 1 is a machine tending station, which holds a CNC milling machine and a five-axis vertically articulated robot designed to work in industrial training facilities. Station 2 is an assembly and quality control station, which has one Robot. This robot has a pneumatic gripper and works in connection with the peripheral station devices such as a ball feeder, a gluing machine and a laser-scan micrometer device. Station 3 is an automatic storage and retrieval system (AS/RS), which contains 36 storage cells and a robot with the ability of taking and placing the work pieces. A conveyer integrates the stations performing the material transport within the cell. The overall system is running with a supervisory host control consisting of a set of station IPC's, a PLC for controlling the conveyor and a host computer that allows management of the cell orders, employing the OPEN CIM software.

Several operations can be executed in the EMU-CIM Lab. For illustration, two operations namely; assembling and quality control are presented below. Any other operations that are received from the host computer can be executed in a similar manner.

The assembling operation, deals with two work pieces; A and B. The system starts with a command from the host computer to the AS/RS for loading the work pieces A and B onto the conveyer. When the parts reach the "assembly and quality control" station, the station's robot takes the parts and puts them in the ball loading position; where four balls are loaded using the robot. At that time, the robot takes the sub-assembly and puts it into the assembling station. The gluing machine starts to work and injects the glue for the desired points on the sub-assembly, and then the robot places part B into the subassembly. The product returns to the AS/RS system via the conveyer and its associated station's robot.

The quality control operations are executed one by one. The system starts with a command from the host computer to the AS/RS for loading a new part (C) into the conveyor. Once the part is received by the "assembly and quality control" station, the station's robot takes the part and puts it onto the laser micrometer for the quality control process. Depending on test results, the robot will place the part into trash box or it will be returned to the AS/RS.

4.6 Design and Development Phase

In order to develop a capability-based data storage system for the desired case study, an "As Is" model at the shop level, needed to understand the manufacturing shop capabilities, is represented using a UML use case diagram. A manufacturing capability general class diagram is used to develop the capability class diagram for the desired shop and the functions, relationships, and attributes are defined. Process, Resource and Knowledge are highlighted as the three building main sub-classes for the shop capability model. UML activity, sequence, object, component and deployment diagrams are employed for modelling resources, processes of the stations and the shop for demonstrating the entire range of information existing in the shop. Furthermore, class diagrams for modelling knowledge relating resources and processes are presented for demonstrating different types of knowledge in the shop.

4.6.1 Defining "As Is' model and establishing system boundaries

The use case diagram is an appropriate tool for creating connections among users and stakeholders of a system. The design and development phase started with an "As Is" model using UML use case diagram. This model explains the system at high levels and does not mention of the details. Figure 8 shows the main use cases of the system which have interaction with the actors. The system is represented by six use case diagrams namely; Machining, Assembling, Quality Control, Execution System, Handling and, Maintenance. It requires three types of actors as followed: Supervisor, Operator and Servicer. One or many of the use cases can be in connection with the actors of the system.

The Operator is kept in touch with the monitoring use cases of the system. This actor is in charge of operating machines and devices of the system. The second actor is the Supervisor who has connections with the control use case of the system. This actor is in charge of controlling and managing stations and shops. Moreover, a Supervisor is responsible for merging internal and/or external activities. The third actor is the Servicer which is connected to the maintenance use case of the system. He is in charge of routine checkups of the machines and devices. Also, in case of any ad-hoc events the Servicer is to be held responsible or be blamed.

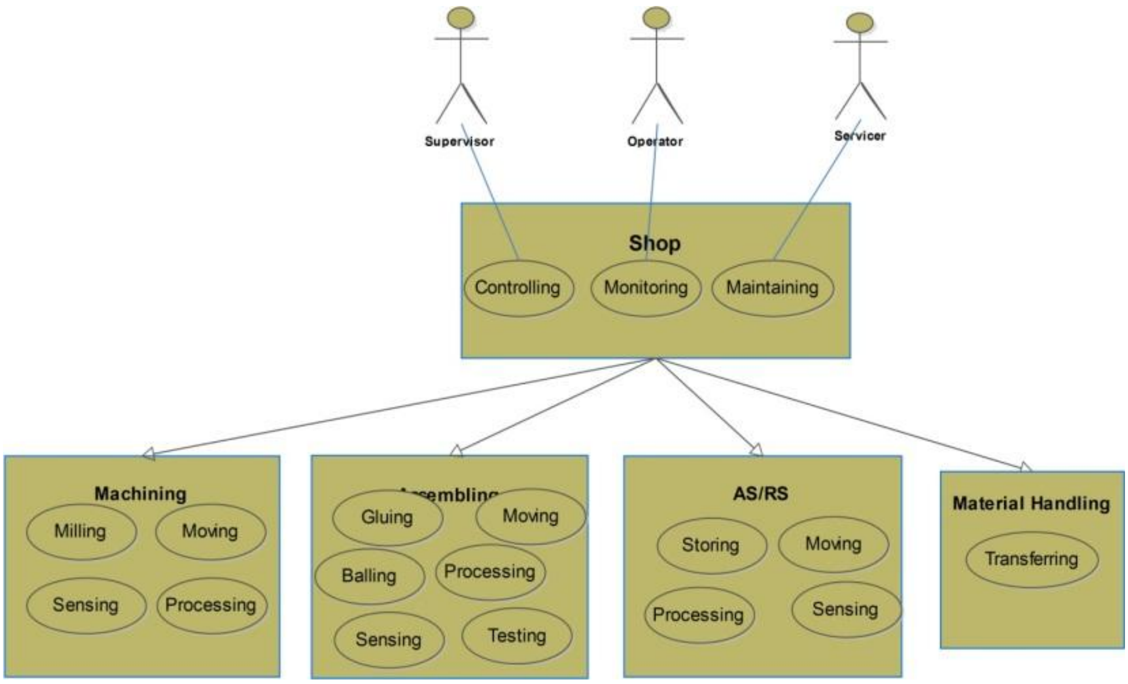


Figure 8-Use Case Diagram

4.6.2 General Manufacturing Capability model

The generic manufacturing capability model in the top-level diagram, [61] composed of all the main classes and their relationships promote the realization of a single conceptual capability model. In the manufacturing capability model, a facility comprises one or many resources, processes and knowledge. Among these, there exist associated relationships. The key role of the associations between classes shows that resources perform processes, and knowledge constraints either one or both resources and processes. Any event of a process is related to one or many instances of the resources features that specify the pre-condition and post-condition of that particular process. Any resource feature can be achieved by one or multiple different processes. Knowledge is partially imposed upon the use of resources and processes.

4.7 Process Modeling

UML activity and sequence diagrams are capable of representing the manufacturing processes of the shop and its stations. The activity diagram is used for graphical representation of work flow of the system. All this can be seen in figure 9 where all the steps and processes for the shop are shown.

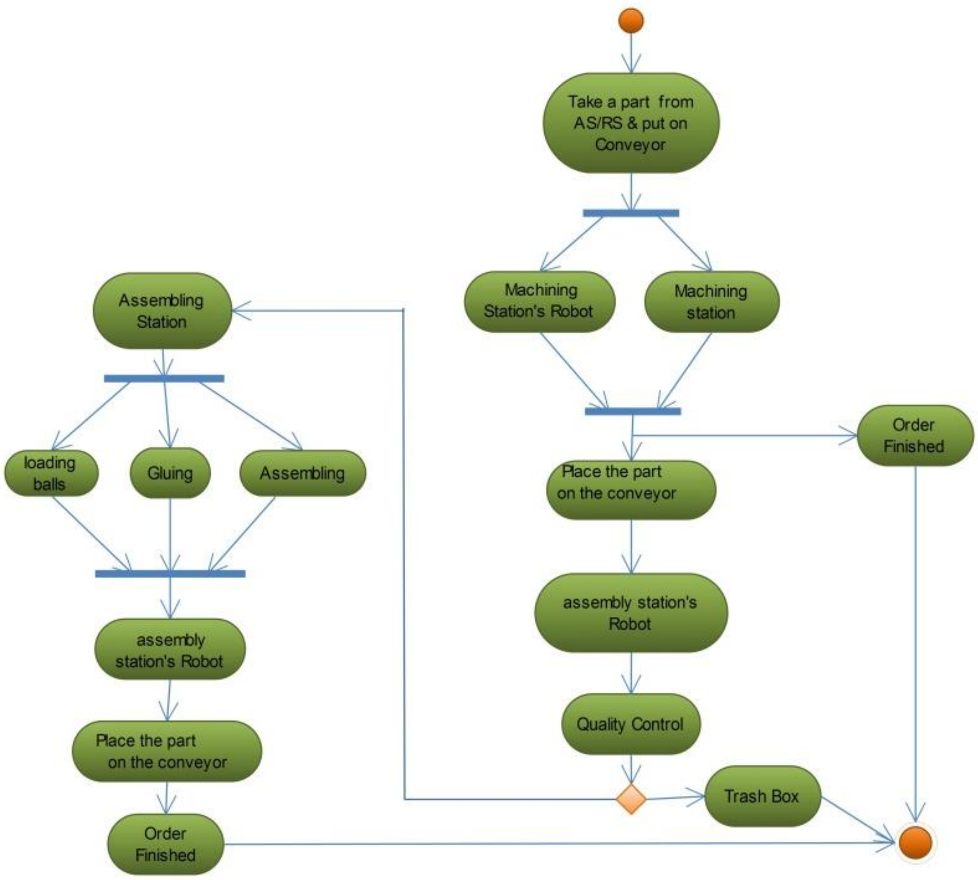


Figure 9-Shop’s Activate Diagram

Sequence diagram is a type of dynamic work flow diagram which shows how processes work together and what the demand (number of pieces) is. It is a plan as well as a message on how to work on the system telling the sequence to follow. The sequence diagram describes the levels of communication in the system. It represents the activities and processes related to each scenario followed by the sequence of messages to be performed on each scenario depending on their need or specification. The sequence diagram of the shop is shown in figure 10. The rectangles represent a manufacturing process and each of the columns demonstrates a manufacturing activity. Depend on the sequence of the processes, arrows connect the processes, the processing duration is bolted on the column based on the duration. Several manufacturing processes based on scenarios can be executed in the machinery and the assembly stations.

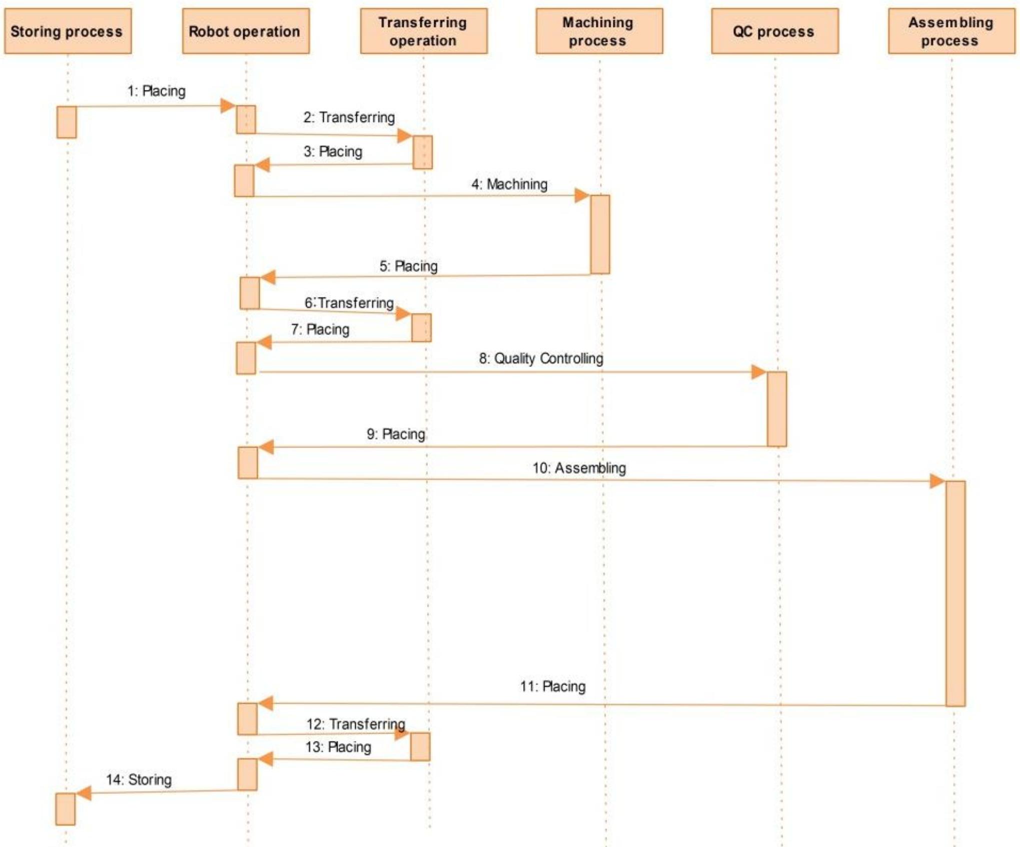


Figure 10-Shop Sequence Diagram

4.8 Resource Modeling

UML object diagrams are used to render a set of objects and their relationships. The purpose of using the object diagram can be summarized as "forward and reverse engineering" object relationships of a system, static view of an interaction, understanding object behavior and their relationships from practical perspectives.

The object diagram of the shop involves the machining, assembling and AS/RS stations that realize the added value processes utilizing the station's resources. The material flow between the stations is realized by a conveyer. Meanwhile, data flow between stations is integrated using a host computer. Each of the stations uses several resources, with the material flow between the station's resources realized by a station's robot. Similar to the shop level the data flow at station level is integrated by the station's IPC. Figure 11 demonstrates the assembly station's object diagram.

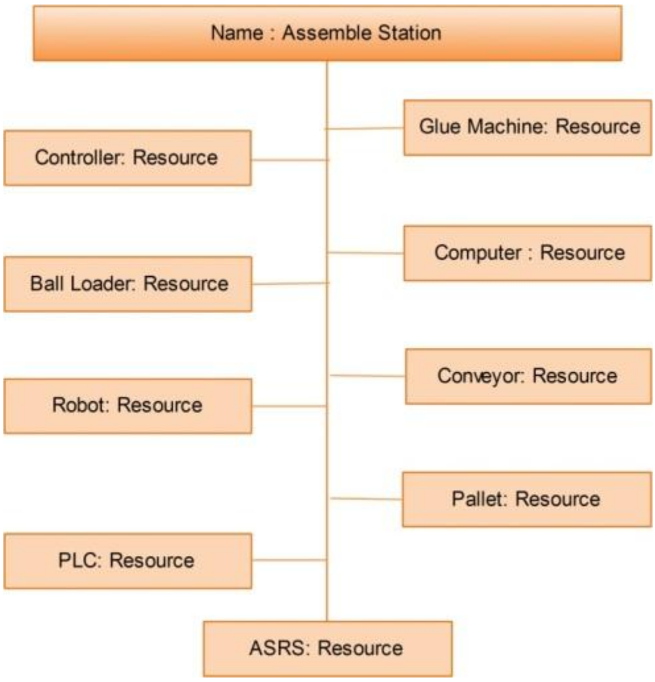


Figure 11-object diagram of the assembly station

4.9 Type of Knowledge modeling

Manufacturing knowledge is an important part of the intended capability-based manufacturing data storage system, since it contains all the process- and resources knowledge identified in the manufacturing shop. Therefore, it is necessary to follow a structure that allows the access and storage of the wide range of manufacturing knowledge. To define these knowledge structures is necessary to explain what process and resource knowledge the manufacturing facility has and how they can be represented. Some examples of collected knowledge are presented to clarify the definitions of knowledge representation used in this work. Graphs, texts, tables, diagrams, formulas are some of the examples for explicit knowledge. While pattern, storytelling, video-clips and sketches are instances for tacit knowledge and implicit knowledge is derived from the performance of a person. Knowledge related to manufacturing processes and manufacturing resources are structured using different types of knowledge namely: explicit process knowledge, tacit process knowledge, implicit process knowledge, explicit resource knowledge, tacit resource knowledge and, implicit resource knowledge.

4.10 Verification Block

The focus of the verification block is on the generation of data files using the developed UML diagrams from the "Design and development phase" and, then comparing the generated data files with the "Preliminary study and problem definition phase" in order to understand whether the designed meets the problem definition or not. The information collected from the operations between "Preliminary study, problem definition phase" and "Design and development phase", is represented in a data file in the extensible Mark-up Language (XML) file format. XML supports the development of the structured data entities that contain a high level of the semantic content, which is both human and machine interpretable. XML is widely used as a file format for manufacturing system data and information modelled using UML and manufacturing simulation software.

In the verification block, XML is the encoding mechanism for the exchange of the file between the "Preliminary study, problem definition phase" and "Design and development phase", and is hereafter referred to as cell data file.

As the UML models are executed, the collected information from the "design and development" phase is transformed into manufacturing data files. The manufacturing data file is the main actor of the matching environment. After the consistency rules are applied, the related manufacturing data file is ready for the matching environment.

The environment that captures the differences of the two manufacturing data files is called the verification environment. Discrepancies between operational representation by "Preliminary study, problem definition phase" and informational representation by "design and development" can be easily captured in the verification environment. The overall information requirements of the cell can be specified by analyzing the difference between "Preliminary study, problem definition phase" and "design and development" with requirement analysis environment.

4.11 Implementation

4.11.1 Transferring the Logical Model In To Physical Data Base

For transferring logical UML models into the physical data base several object-oriented languages and tools are available. JDeveloper is used to transfer the logical UML models into the Object Store© data base.

4.11.2 Capability-Base Decision Support System

To realize decision making processes with associated capability- based information and knowledge systems, an appropriate Capability Analysis Tool (CAT) has been developed. Figure 12 illustrates the transaction of the processes for the CAT. Detailed processes are described below. The numbers in the figure stand for the index of each process.

Step I: the order related component specifications (feature-based) are loaded into the "Capability Engine" to generate the required capabilities for the order (1)

Step II: when the system wants to know availability of the required capabilities within the enterprise, the CA Tool is triggered and acquires capabilities which, newly generated on the previous steps are sent to the CA Tool (2).

Step III: the CA Tool checks the enterprise capability based systems and if the required capabilities are not available within the enterprise, the CA Tool returns a corresponding message to the order. (3).

Step IV: if the required capabilities are available in the enterprise, the information related to resources, activities and corresponding knowledge are obtained from the enterprise capability based systems(4). The CA Tool suggests appropriate capability plans for the required capabilities by invoking the information and knowledge of the Step III.

Step V: with the CA Tool results, the potential required information and knowledge for the order is highlighted and ready for the decision making process.

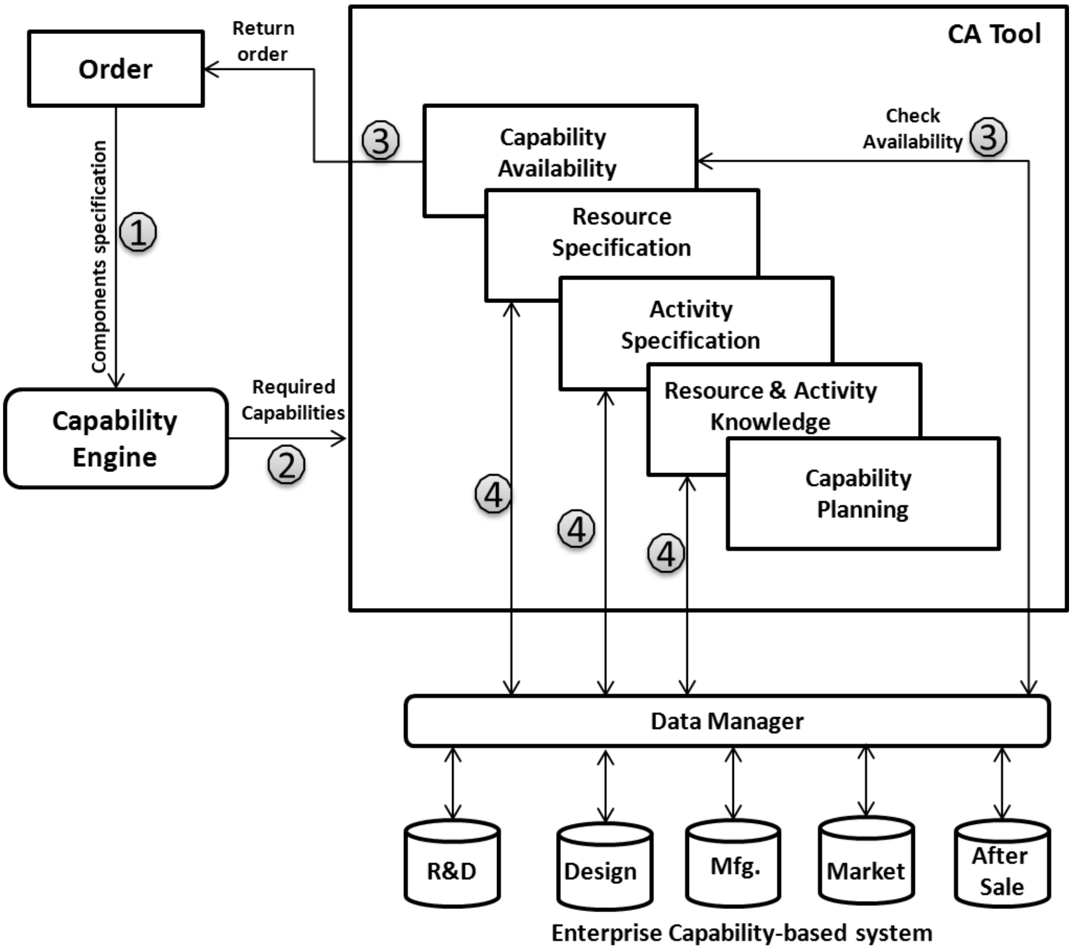


Figure 12-Capability analyses Tool Architecture

Chapter 5

ENTERPRISE COMPETENCY: FROM THEORY TO PRACTICE IN ENTERPRISE ARCHITECTURE

5.1 Overview

Enterprise competency refers to knowledge that describes the skills and abilities possessed by a particular enterprise. This paper proposes a new framework for intra-enterprise competency modelling. First, formal definitions of enterprise competency and related aspects (i.e. resource, activity, and knowledge) are presented. Second, conceptual sub-categories (i.e. capability, cross-functional co-ordination, and cross-functional integration) are discussed for the purposes of capability and competency modelling. The framework is illustrated by developing a competency knowledgebase for a bicycle plant with two sectors. The competency knowledgebase provides information important to decision-making, and can act as an indicator for an enterprise's willingness to engage in robust collaboration.

5.2 Introduction

Researchers have explored the importance of enterprise Competency in several ways: by suggesting core Competency models to sustain competitive advantage [62,6], by building on the concept's basic tenets to invent similar concepts [63,7], and by developing processes for its identification and management [1,6]. One body of existing work focuses on ways to empirically model competencies using company task-forces and resources, as well as capability concepts as part of the identification and management process [64,65].

Ermilova and Afsarmanesh (2010) recognises three levels of abstraction for Competency modelling: (1) intra-enterprise, (2) inter-enterprise, and (3) network. The major motivation for enterprise competency modelling is at network level (i.e. Collaboration Networks (CNs)) [66]. In the creation phase of a network, it is vital to have a robust enterprise knowledge base embedded with partners' competencies. Most competency modelling purposes are typically considered at these three levels [67] .

Because only a few experiential studies exist on the topic, it has recently been suggested that there is a lack of knowledge about enterprise internal Competency modelling [68,69].In small size enterprises, enterprise competencies' modelling is typically based on oral information and general applications. In more complex enterprises, however, Competency modelling on a human basis is not any more effective [70].

Extant research has been valuable for clarifying Competency, effective Competency management practices [71] and the ways in which enterprise competencies can be identified [72,73].However, one shortcomings of the literature is the lack of clear empirical definitions for associated concepts (e.g. resource, capability). In addition, a significant contribution is made for competency modelling and management at concept and/or basic levels, and there has been a small number of contributions to enterprise competency modelling at tangible detail-level [63, 74]. Moreover, there has been a substantial amount of research within managerial sciences and industrial engineering [75, 76] related to enterprise competency modelling and management, but few of these efforts have considered enterprise competency from an enterprise information technology perspective. Instead, research within these domains has largely focused on manufacturing companies. From this brief state of the art, a major need appears that is not only clarifying competency related ‘associated concepts’ but also detail modelling of enterprise competency from IT points of view.

A framework has been developed to model intra-enterprise competency to provide important decision-making information for the people with moderate knowledge on enterprise engineering. It can be derived and adapted to every enterprise’s need. This framework was applied to a bicycle plant with two sectors. For do this, we first analyse the concept of competency and its aspects (i.e. resource, activity, and knowledge). Next, intra-enterprise competency modelling sub-categories (i.e. capability, cross-functional co-ordination, and cross-functional integration) are presented in terms of its entities and relationships. Then, we discuss the necessary steps for operationalizing this framework through a case study. Finally, we present a relational knowledge base model of the case study and its various functionalities and offer some concluding remarks.

5.3 Enterprise data infrastructure

An enterprise’s data infrastructure is a layered set of data that provides a foundation for strategic initiatives such as: (a) outlining the business's aims and objectives for improved collection and use of data, (b) improving business processes, (c) making decisions regarding the future of new and changed systems, and (d) integrating, warehousing, and reporting initiatives. An enterprise data infrastructure is not fully represented by a set of detailed models of individual systems, because the models cannot convey the macro-level information required to meet the stated strategic initiatives. Additionally, top-level models cannot be used exclusively, as they fail to include sufficient detail for answering important questions. Instead, enterprise data infrastructure is mapped as a generic tree structure to model existing enterprise data. To highlight enterprise competency, the infrastructure proposed in this this paper is shown in Figure 13. The infrastructure has been divided into four key tiers: Enterprise General Information, Enterprise Workplace Information, Enterprise-wide Technical Information, and Manage Effectiveness Information. The infrastructure representation begins with Enterprise General Information, which captures basic information about the enterprise. Enterprise General Information contains four sub-classes of information, including enterprise name, enterprise story, address(s), and key persons. The second tier, Enterprise Workplace Information, is intended to capture the market details of the enterprise. It includes information about the sector (e.g. mining and farming, construction, manufacturing), the products/services offered by the enterprise, both existing and target consumers, and commercial financial highlights (e.g. revenue, profit, income, employees). The third tier is Enterprise-wide Technical Information, which is intended to capture an enterprise's competencies. Competencies consist of all assets, tangible and intangible, human and non-human, that are possessed and controlled by the company that permit it to devise and apply value-enhancing strategies [77]. The Enterprise-wide Technical Information tier contains three sub-classes, including processes, resources, and knowledge related to process [43] and resource(s). The Manage Effectiveness Information tier contains the information that an enterprise publishes to draw the attention of consumers and vendors for new business opportunities. The subclasses included in this tier are: past projects, relationships (e.g. relevant with other enterprises), and achievements (e.g. parents, standards). The focus of this paper is on the third tier of this infrastructure.

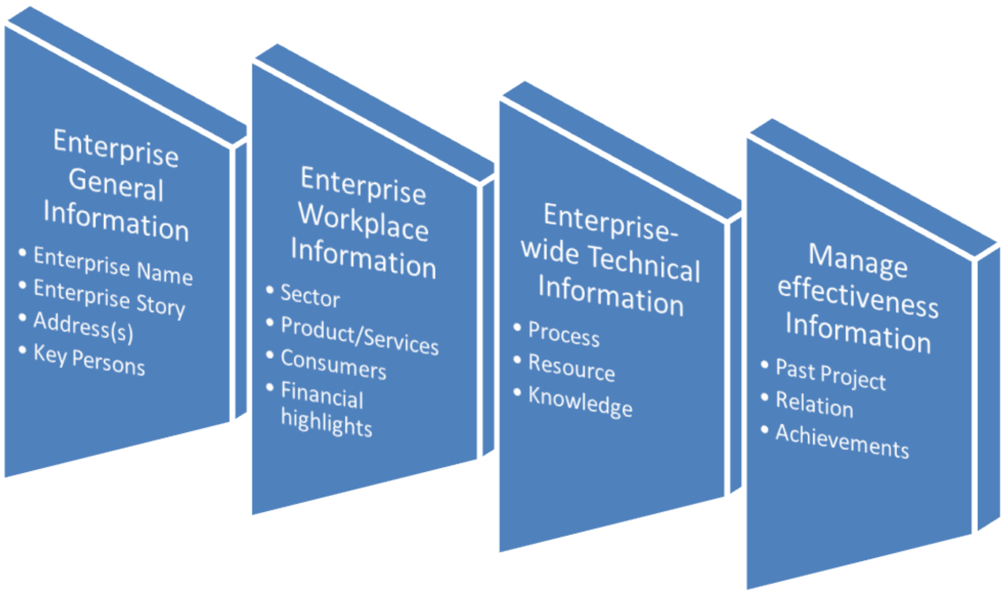


Figure 13-Enterprise data infrastructure

5.4 Competency: Sub-categories and modeling aspects

Enterprise competency models are generally used for representing relevant business activities and products or services offered by a company [77]. In this chapter, we use Javidan's enterprise competency definition to explore competencies 'across functional co-ordination and integration of capabilities'. This definition includes three broad sub-categories: coordination, integration, and capability. First, coordination, according to Mooney and Reelay 1998, 'is orderly arrangement of activities to provide unity of action in the pursuit of common goals within a sector'. Second, integration is defined as 'establishing mechanisms and links that facilitate the needed integration of the activities of different functions to ensure that these functions work together effectively to achieve the overall objectives of the enterprise' [78]. Finally, capability is defined as: a sector's capability is represented by a set of information that is embodied by all available resources and corresponding activities that can be performed by those resources, as well as the knowledge about how these resources and activities can be used effectively, efficiently, and economically.

One major difficulty associated with modelling enterprise competency is the ‘Cross Functional co-ordination’ and ‘Cross Functional Integration’ of the sectors' capabilities with varied backgrounds and priorities [1,6,43]. For example, in a manufacturing enterprise, capabilities of the design sector often fall in the domain of striking aesthetics, the manufacturing sector is drawn toward standardised designs, the research and development (R&D) sector scientists are drawn toward novel technological applications, and the marketing sector seeks industry benchmarks and requirements for customer satisfaction. These different orientations may generate priorities that are opposed to one another, resulting in uncooperative behaviours for cross functional coordination and integration of the capabilities. Unsurprisingly, ‘cross-functional co-ordination’ and ‘cross-functional integration’ in sectors' capabilities has become a challenging concern for enterprise competency modelling. In particular, there are two important issues for enterprise competency modeling. First, what are the best methods for strengthening ‘cross-functional co-ordination’ in sector’s capabilities? Second, what are the best strategies for strengthening ‘cross-functional integration’ in sectors' capabilities within the enterprise? Figure 14 illustrates an enterprise competency model in terms of sectors' capabilities, ‘cross-functional co-ordination’ and ‘cross-functional integration’. As shown in this figure, from bottom to top, each sector contains one or many capabilities origin from its divisions. These capabilities are ingredients for ‘cross-function co-ordination’ process aiming to generate a sector’s capability. The ‘cross-functional integration’ process on the sectors capabilities will result enterprise competency.

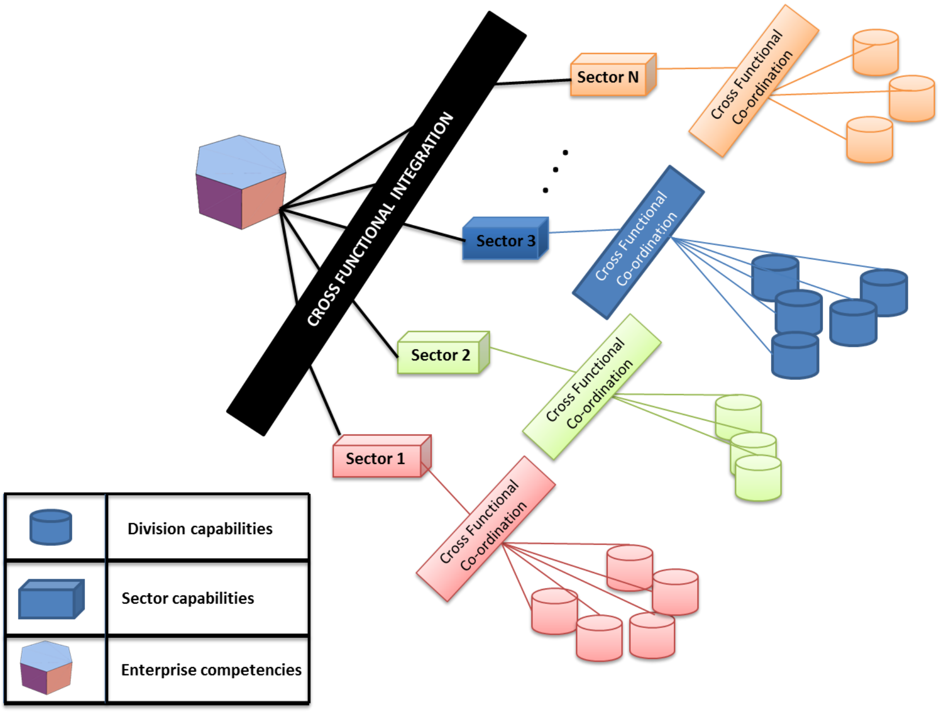


Figure 14-enterprise competency sub-categories

5.5 Proposed Multi-level intra-enterprise competency modeling framework

In this section, a multi-level framework is developed to capture, and model enterprise competency. This framework is based on a set of aspects and sub-categories required to describe enterprise competency. For the sake of consistency, we have named our framework the Multi-Level Intra-Enterprise Competency Modelling Framework and adopted the abbreviation MICMF for use throughout the text. MICMF is based on three high- level concepts that collectively represent an enterprise's competency (see Figure 15).

• **Basic Integration and Cooperation Level (BIC)**. The BIC captures fundamental aspects information regarding each sector's competency. The fundamental aspects of information for competency are resource(s) information, activity(s) information, and knowledge related to resources and processes.

• **Sector's Capability Functionalities Level (SCF)**. SCF intended to model sector capability in accordance with sector-specific goals. In other words, the SCF deals with modelling the capabilities of sectors at division layers towards the accomplishment of its assigned capabilities for intra-enterprise competency.

• **Intra-Enterprise Competency Functionalities Level (ICF)**. ICF is intended to accomplish the 'cross functional co-ordination' and 'cross functional integration' processes on sectors' capabilities in accordance to each sector specific goal and the enterprise global goal(s).

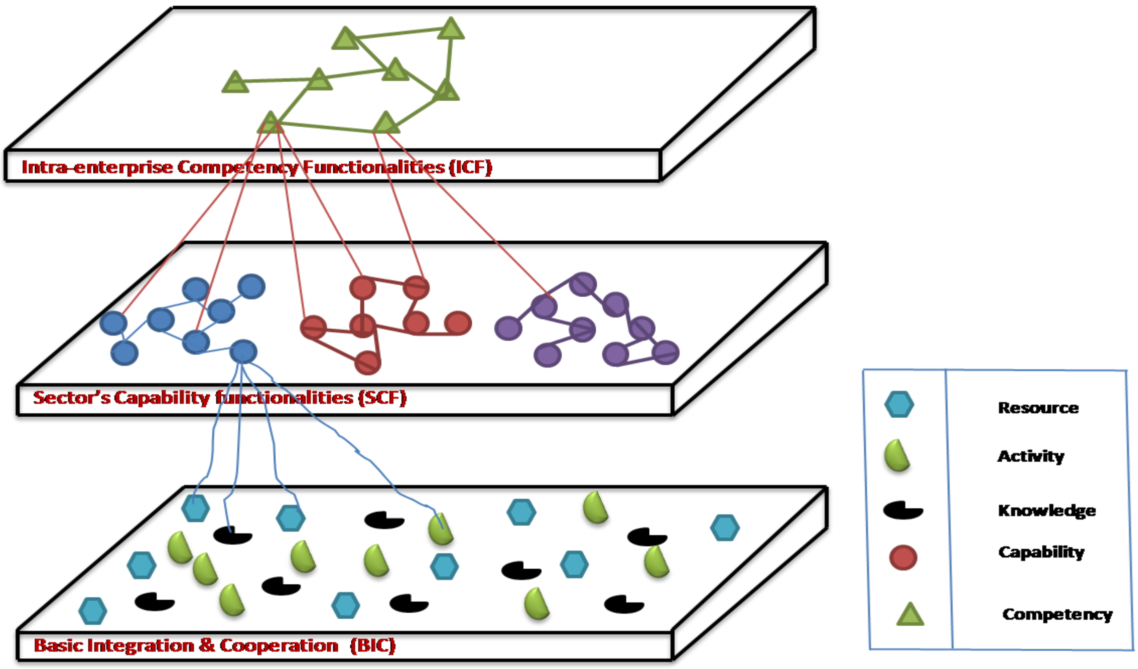


Figure 15- Multi-level intra-enterprise competency modeling framework

As shown in Figure 15, MICMF contains BIC, SCF, and ICF levels. In MICMF, each level's output is input for the next level. These graphics are intended to represent a sequence of level attainments, which begin at the bottom level and work upward. The inputs for the BIC level are resource(s) information, activity(s) information, and knowledge. The BIC level assigns suitable data to the appropriate capabilities.

Ultimately, the output produced at the ICF level is enterprise competency. The SCF level is in charge of sectors capability modelling. Based on capabilities from the previous level, the key responsibility of the ICF level is enterprise-level competency modelling. The interface between the levels is shown with thick and break lines, where a thick line represents capabilities associated aspects information. Break lines illustrate sector-level capabilities. Next, BIC, SCF, and ICF levels of the MICMF are clarified in detail.

5.5.1 Basic Integration and Cooperation Level (BIC)

Capabilities are scattered throughout an enterprise's various sectors [79]. Because a capability can be decomposed into a hierarchy of sub-capabilities, the sector's capabilities must be considered at different levels of abstraction [80]. To structure a sector capability, four levels have been defined: Division, Group, Class, and Subclass .The use of four levels is consistent with the classification structure of CPC (defined by the UN Statistical Division).

As an example in a manufacturing enterprise:

> Sector: Department (e.g. production department, design department)
>
> Division: Factory of a department (engine factory of production department)
>
> Group: Shop at a factory (e.g. crank shaft shop at engine factory)
>
> Class: Cell at a shop (e.g. crank shaft grinding cell at crank shaft shop)
>
> Subclass: Station at a cell (e.g. centre less grinding station at the crank shaft grinding cell).

Within the literature, several terms indicate the fundamental aspects of competency, including production skills, technologies, resources, capabilities, processes, and actors. Boucher et al. 2005 consider professional situation, actor, and resource in their analyses. Mueller 2006 [17] considers humans, resources, and fulfilled tasks as fundamental components. The authors adapts the Molina, Ellis, et al. (1999) research on manufacturing data modelling, and distinguishes resource, activity, and knowledge for each of the sectors within the enterprise as the fundamental aspects for enterprise competency.

The basic premise of BIC is to organise enterprise data as set of distinct components that can be independently gathered to develop a variety of capabilities through the combined components. From a top-down perspective, capabilities implemented by a sector are usually organised in to “clusters” of inter-related capabilities from different divisions, groups, classes and subclasses these capabilities have heterogeneous data type that is often hard to interoperability [81].

Assume a sector contains capabilities, SC= { , , …, } and a capability consists of divisions , =(, ,…), where is a sub-capability a division j in capability *i* and contains groups , =(, and classes, =(, ,…,). For each capability at class layer, at the subclass level there are three distinct compounds: resource, process, and knowledge.

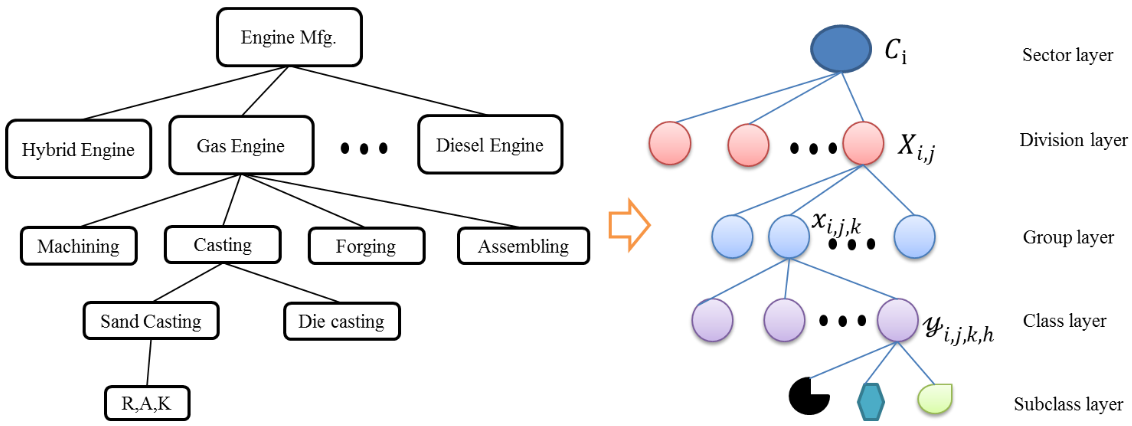


Figure 16-shows the functional hierarchy for engine production capability and the hierarchical levels for representing this capability.

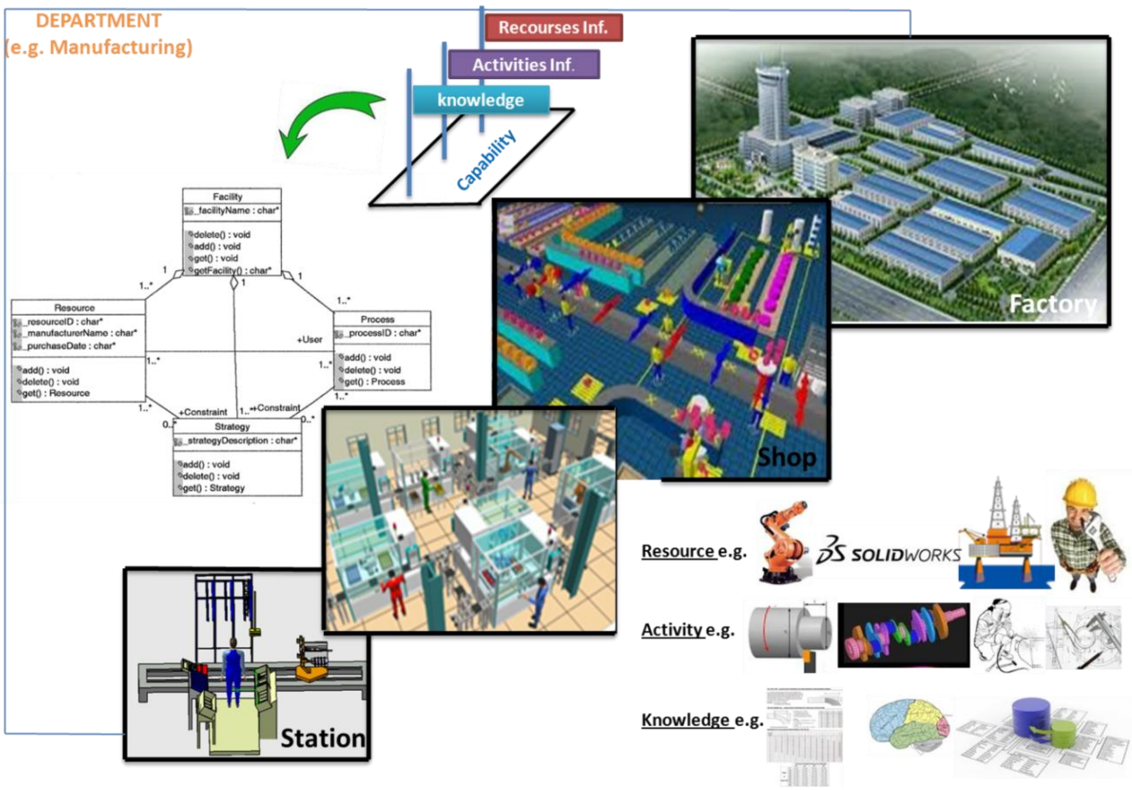


Figure 17-Functional hierarchy and capability representation

5.5.2 Sector's Capability Functionalities (SCF)

The basic idea for the SCF level of MICMF is capability modelling. A generic sector capability model in the top-level diagram, which is composed of all the main classes and their relationships, makes possible the realisation of a single conceptual capability model. A sector capability model is illustrated at Figure 18, where a facility is considered to be comprised of one or many resources, activities and knowledge. Among resources, activities, and knowledge, there are many associated relationships. The role names of the associations between classes show that resources perform activities, and knowledge constrains both resources and activities. The hierarchal structure for resources has been modelled as: human, physical resources, ICT and organisational resources. In the same way as for the resource class, an activity hierarchal structure has been identified, as has the relationships between classes. Any one instance of an activity is related to one or many instances of the resources features that specify the pre-condition and post-condition of that activity. Any resource feature can be achieved by one or multiple different activities. Knowledge restricts the use of resources and activities.

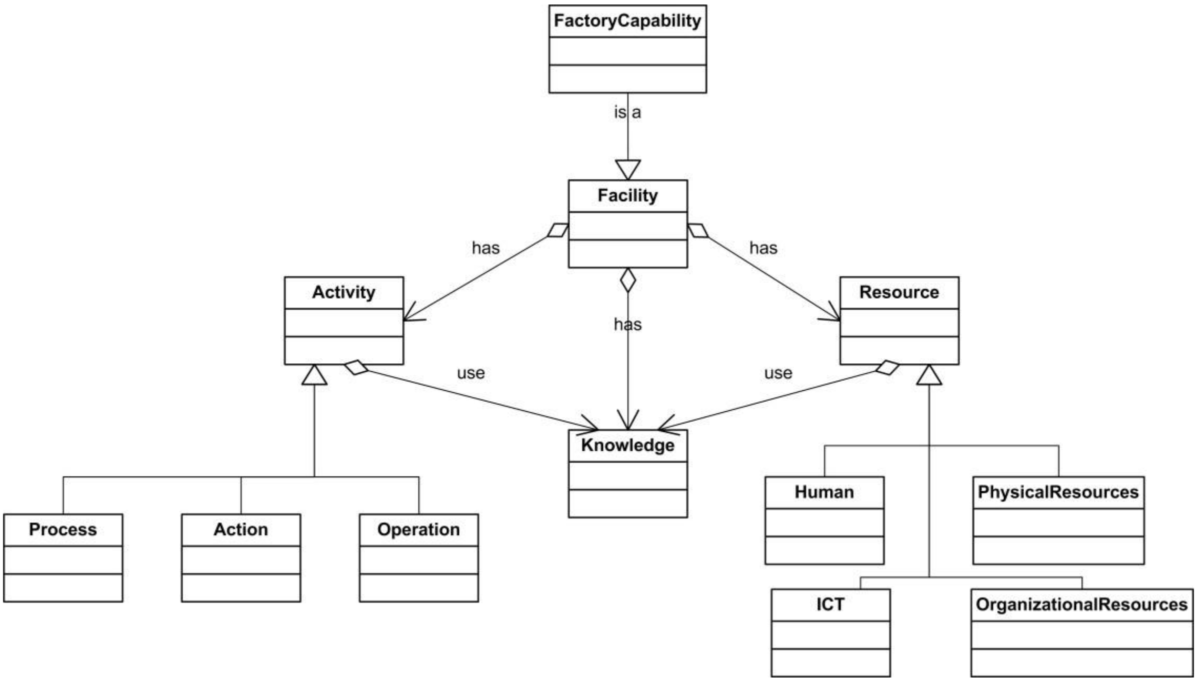


Figure 18-Sector capability model (Guerra-Zubiaga and Young, 2008-a)

The formalisation of sector capability is as follows. Let‘s consider for subsequent modelling a set of sectors at an enterprise E= {S1, S2, S3, …}.

Definition 1 (**Sector capability**)- Capability can be understood as sector's ability to perform activities, tasks, acts or processes possible through corresponding resources and knowledge, aimed at achieving a specified number of outcomes.

For modelling the remaining concept, let's consider the set of capabilities at sector α: in which each element stands for a capability. The following definition introduces the concept of capability, which is built upon three building aspects. It can be specified as a set

, i=1…n

Such that:

, i=1,…,n ,

j=1,…,m

,

i=1…n, j=1,…, m

, i=1…n,

j=1,…, m

Definition 2 (**Sector's task-oriented capability**) - A sub-set of a sector capabilities set, this sub-set represents capabilities which are needed to run a specific outcome or specific goal.

For sector α it can be shown as where:

{ ;

k=1,…, n

5.5.3 Intra-Enterprise Competency Functionalities (ICF)

The basic idea at ICF level of MICMF is 'Cross functional co-ordination' and ' Cross-functional integration' of capabilities. Cross-functional co-ordination of capabilities of a sector has been identified as a key operation for enterprise competency creation process [17]. The successful achievement of the enterprise's global goals depends not only on the appropriate co-ordination of sectors' capabilities, but the proper integration of the capabilities at enterprise level is also vital. Additionally, a potential defect in one node (sector capabilities) may jeopardise the enterprise competency model. As shown in Figure 19, the competency may, on its (their) turn, be decomposed into several sub-capabilities whose activities are supported (performed) by various service functions available in the sectors. The interdependencies (sequence/parallelism, synchronisation, data flow, precedence conditions) among capabilities, at the various sectors, must be properly integrated in order to achieve the enterprise global goals. 'Cross-functional co-ordination' and 'Cross-functional integration' of capabilities is defined as:

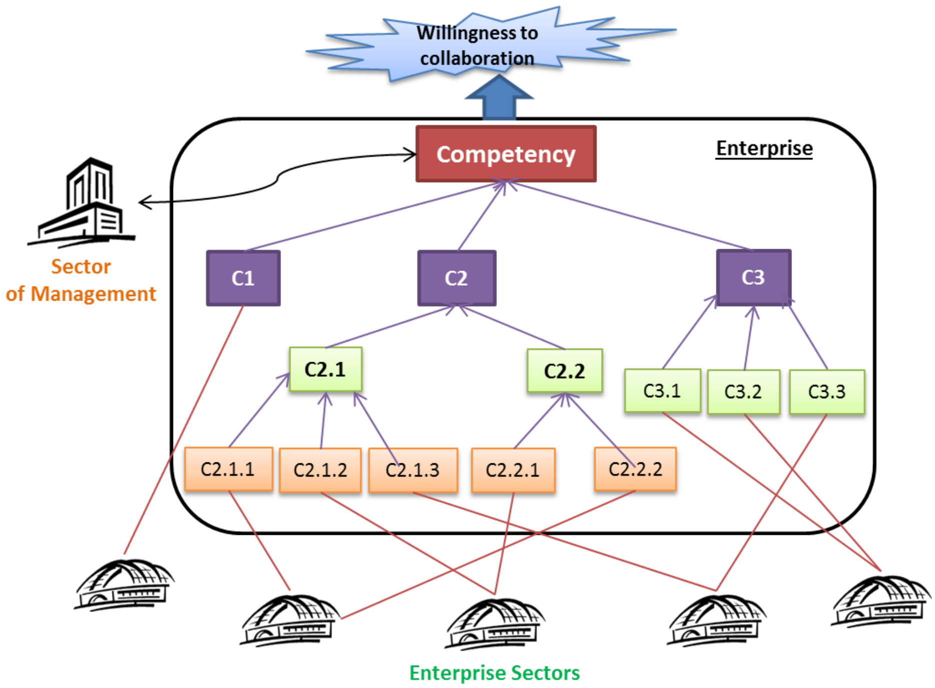


Figure 19-Cross functional integration/ cooperation

Definition 3 (**Cross Functional Co-ordination (CFC) of capabilities**) – is a link among capabilities within a sector, this link seeks to fund relations between the activities of the capabilities using sector's 'product/service workflow diagram.' CFC is act as union for the other component of the capability (i.e. resource

, knowledge ,).CFC is the set of

ordered pairs ; where is the independent activity and the is dependent on .

Where:

- C- is a capability set

- x,   - is a activity, task, act or process

Definition 4 (**Cross Functional Integration (CFI) of capabilities**) - CFI is a link among capabilities of sectors within an enterprise. This link seeks to fund relations among the activities of the capabilities at the enterprise using enterprise's 'product or service structural model'. CFI acts as union for the other component of the capability between sectors (i.e. resource , knowledge ,).

Definition 5 (**Enterprise's competency)** –Is defined as cross functional co-ordination and integration of task-oriented capabilities aimed at achieving a global outcome or goal.

Enterprise's competency definition can be formulated as:

Where:

- G- Represents a specific outcome or goal.
- 1, 2, 3,…, n- Is an index for representing sectors.
- - Task-oriented capability for Sector m as defined previously.
- .
- cross functional integration and co-ordination
    - - Cross Function Integration between sector n and sector m.
    - CFC- Cross Function Co-ordination.

5.6 A case study

The manufacturing system where this case study was carried out is in the custom-designed bicycle industry. This industry has been operating for over fifteen years in Cyprus and has a growing market demand -generally of European origin- for its products. To exemplify the operation of the MICMF, let’s deliberate on two sectors in this industry. These sectors cooperate to design and fabricate a new bicycle’s frame. In this scenario, sector A prepares detail model of the desired frame using a CAD system and defines some additional characteristics for this part. This technical specification is then sent to sector B. Sector B might accept the proposed design or suggest changes that have to be negotiated with sector A until an agreement is reached. Finally, sector B is responsible for fabricating the frames. Competency modelling objectives at this example concern the identification, updating and exploitation of the intra-enterprise competency. The framework of Figure 15 was adapted to the domain study.

MICMF are grouped into three operational levels, which facilitate the competency modelling. These levels groups tasks according to their competency modelling aspects and/or sub-categories. Each level is useful in certain situations.

BIC Level:

a) Identify and list required capabilities of the sector,
b) Assign resources, activities and knowledge to the sequenced capabilities.

SCF Level:

a) Interactions of capabilities within sectors and between the sectors
b) Sector capability model.

ICF Level:

(a) Cross-functional co-ordination of capabilities within a sector, and Cross-functional integration of capabilities between sectors
(b) Competency representation

BIC Level:

a. Identify and list required capabilities of sector.

The first step for competency modelling is identification and evaluation of the exist capabilities at the sectors. Work-station oriented (or goal-oriented) approach is used for identification and evaluation of necessary and acquired capabilities at the sectors. This process include four stages(1) analysis of goal; (2)deriving the structure of goal; (3) determination of the various capabilities needed to overcome goal; and (3) sequencing those acquired.

There are methods for identification and evaluation of necessary capabilities at a sector. Among the existing methods, the observation, the description, the interview, the method of the critical incidents and the grid of Kelly can be mentioned [43]. The method used here to identify capabilities is based on the interview approach. In this example the goal of the sector A is design, prototyping and testing a new bicycle's frame and for sector B is fabricate and quality control of the new frame. Furthermore, the enterprise global goal is offering a new designed bicycle to the market. After identification process, the listed capabilities are then sequenced so that they follow the order in which they will be performed. Successful completion of these attempts often requires a good knowledge of process planning, manufacturing features and manufacturing resources. In this example, and are the set of capabilities for sector A and B of the enterprise, respectively:

={'Cutting','Forming','Joining','Weighing','Painting','Finalization','Quality control'}

= {'Concept design', 'Prototyping', 'Analysis',' Test', 'Detail design'}

b. Assign resources, activities and knowledge to the sequenced capabilities

To complete the BIC level, it is necessary that the resources (e.g. machines and tools) and activities (e.g. manufacturing processes), as well as the knowledge that is needed for each capability are assigned. For the resources, activity and knowledge assign processes of acquired capabilities, interviews of personal appreciation, samples, references is used. The ‘Detail design’ at sector A furthermore ‘Cutting’ and ‘Forming’ capabilities at sector B have the following sub elements:

‘ ’=

‘ ’=

=

‘ ’=

=

=

Table 2and 3 demonstrates the assigned resources, activities, and knowledge for the capabilities of the sectors.

Table 2-the resource, activity, and knowledge assuaged to the capabilities at sector A

Concept capability		
Resource	***Process***	***Knowledge***
Drawing tablet Drawing tools technical software designer type 1	Quick sketching a few concepts Shading and refining Choosing-one 3D modeling Refining 3D model	Design skill
Prototyping capability		
Rapid prototyping machine common hand tools technician type 8	Proof-of-Principle Prototyping Form Study Prototyping User Experience Prototyping Visual Prototyping Functional Prototyping	prototyping technical worksheet RP machine manuals
Test and analysis capability		
Static test apparatus Dynamic test apparatus ABAQUS software Aerodynamic test apparatus technician type 8 Technician type 9	Static test Dynamic test Structural analysis Aerodynamic test	ABAQUS document Static test worksheet Dynamic test worksheet Aerodynamic test worksheet Static test apparatus manual Dynamic test apparatus manual Aerodynamic test apparatus manual
Detail design		
CAD	part design assemblies design drawing	Detail design skill

Table 3-The resource, activity, and knowledge assuaged to the capabilities at sector B

Cutting Capability		
Resource	***Process***	***Knowledge***
Center Cutting fixture Curve Cutting Fixture Tool1-Tool2 Cutting Machine1 Cutting Machine2 Technician type1 Technician type2	Center Cutting (CC) Curve Cutting(CuC)	Cutting Machine1Manual Cutting machine2 Manual Center Cutting Process Hand Book Curve Cutting Hand Book
Forming Capability		
Tube forming Die Tube forming press bending machine Technician type3 Technician type 4	Tube forming Bending	Tube forming process Hand Book bending process Hand Book Tube forming press manual
Joining capability		
oxyacetylene welding system welding fixture	Gas welding	welding process Hand Book welding machine manuals

electrode technician type5		
Painting capability		
hand abrasive machine painting oven technician type 6	paint preparation painting	paint preparation worksheet painting oven manual
Finalization Capability		
technician type 7 cleaning machine	Cleaning Labeling	cleaning worksheet Cleaning machine manual
Quality control capability		
Ultrasonic NDT machine technician type 7	NDT testing	testing worksheet Ultrasonic NDT machine manuals

SCF level

a. Interactions of capabilities within sectors and between the sectors

Clarification of the interactions between the capabilities within the sector and among sectors of an enterprise is vital since it will be used at next level of the framework. For simple cases, numbers (also called capability numbers) indicate the sequence in which the capabilities will take place. For example, in sector B, first the cutting capability must be finished, and then the forming capability, before painting capability takes place. Sometime a capability can have a flexible sequence and sometimes, two or more capabilities can take place simultaneously. In a similar way, specific interactions between the capabilities have to be done for each of the sectors of the enterprise. For a case with numerous interactions between the capabilities sequence diagrams are applicable for this purpose. Figure 20 and 21 illustrates the sequence diagrams for the interactions of capabilities within the sector A and B. Furthermore, the sequence diagram in Figure 22 demonstrates the interaction of capabilities among sector A and B.

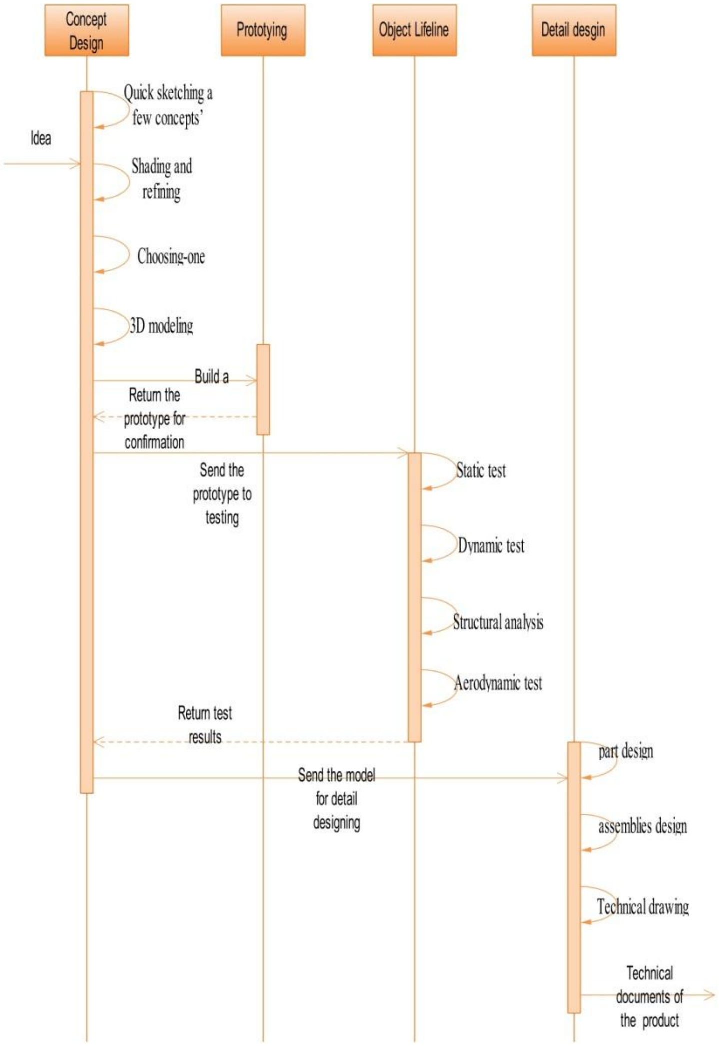


Figure 20-interactions of capabilities at design sector

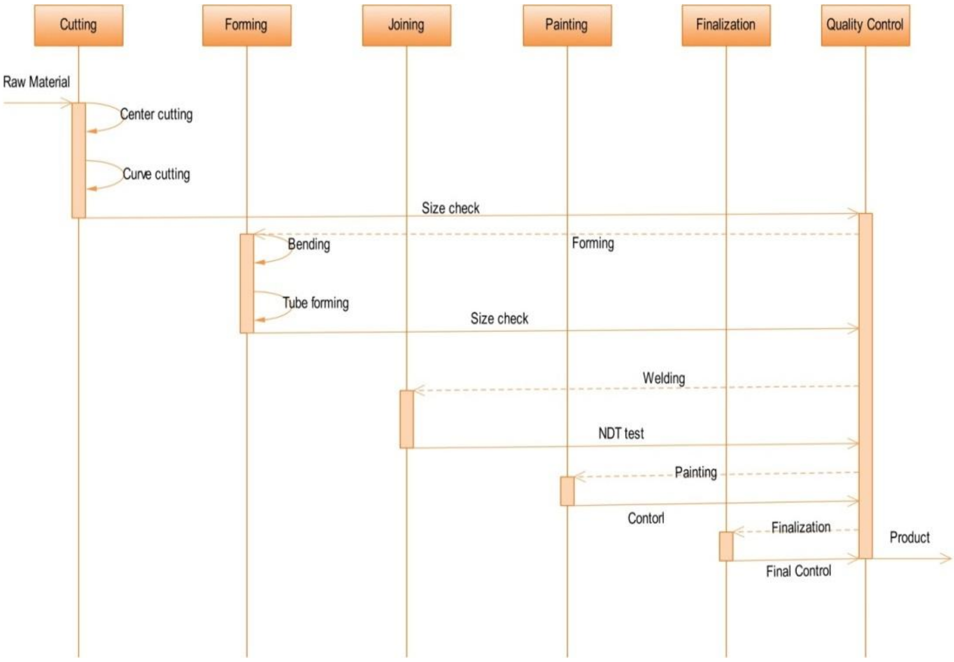


Figure 20-interactions of capabilities at manufacturing sector

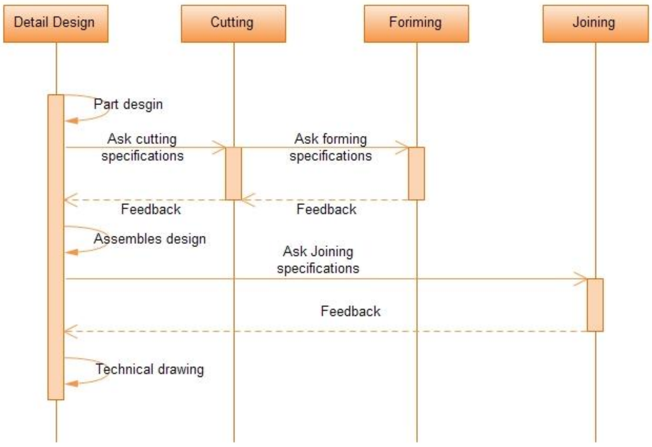


Figure 21-interactions of capabilities among the design and manufacturing sectors

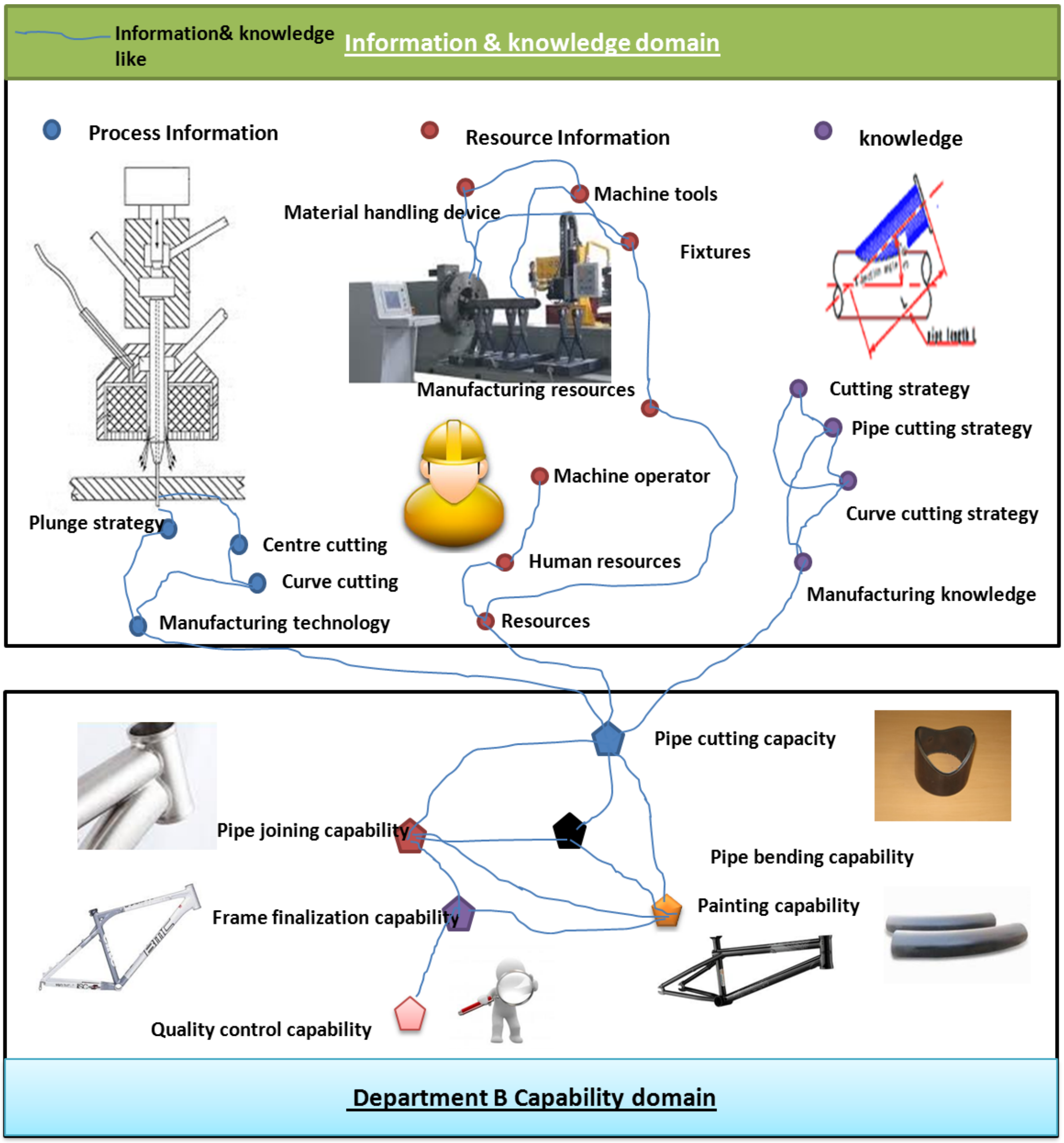


Figure 22 'pipe joining capability' at department B for bicycle frame

b) Capability modelling

To store competency aspects in a structural manner, it is significant to model the capabilities within the sectors. Thus the study has been oriented to create capability models. The capability model which is introduced previously (definition3) was adapted to all the identified capabilities at the enterprise. This model is used to capture all the aspects (i.e. resource, activity, and knowledge) of the capabilities. Figure 22 shows what a more comprehensive and detailed the cutting capability would look like when performed with a model.

A capability knowledgebase is developed to assure that the knowledge of capabilities at the sectors is capitalized. At present, the knowledgebase is developed under ACCESS and is operational. The relational model of the capability knowledgebase is represented by Figure 24. The use of a standard incoming application adds knowledge gathering process (Figure 25) to the capability knowledgebase system.

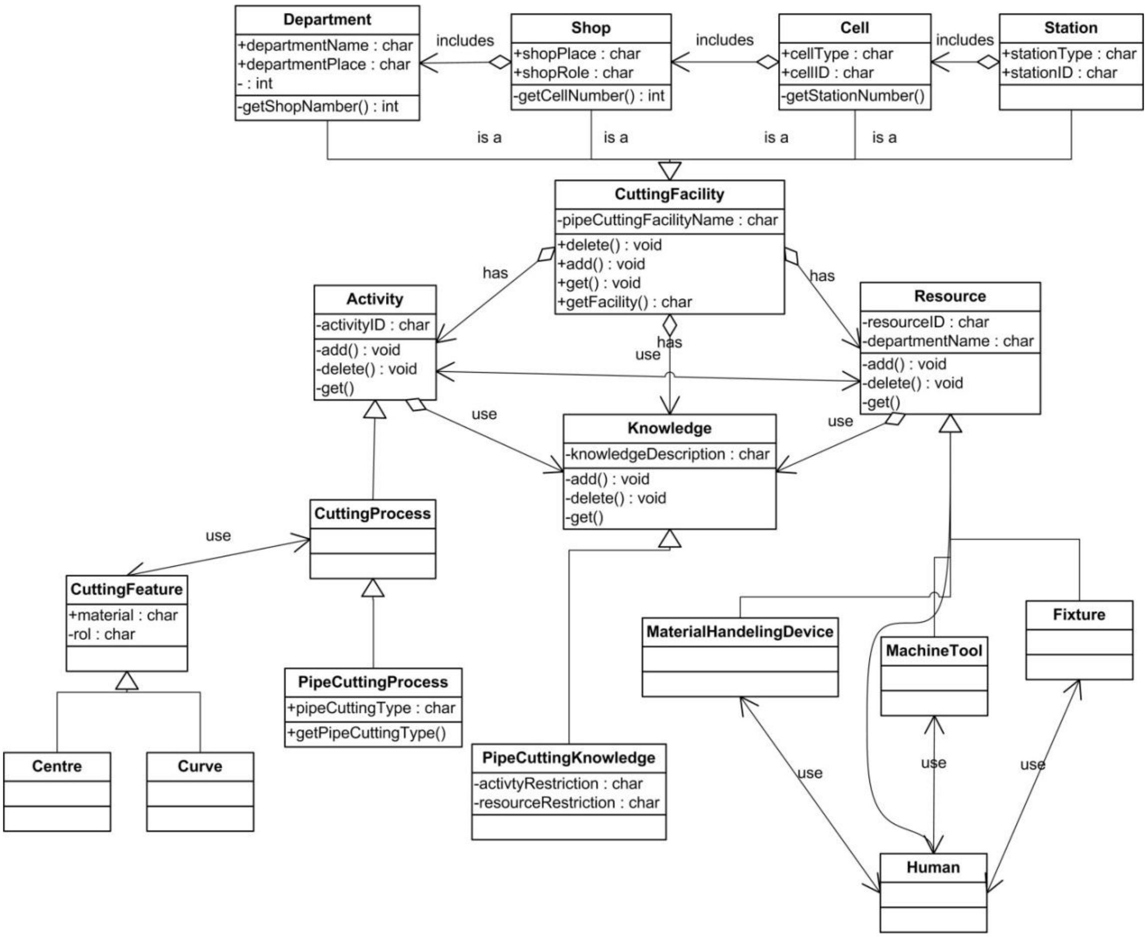


Figure 23-the capability model for the cutting capability

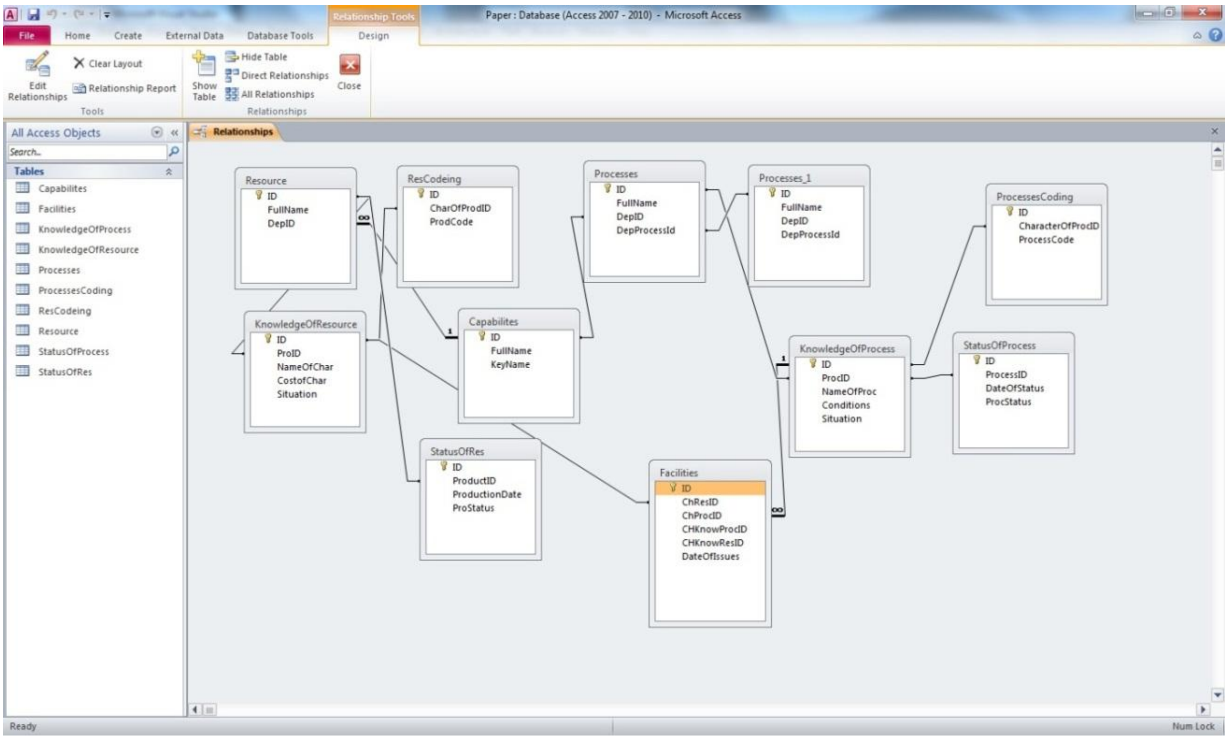


Figure 24-relational model of capability knowledgebase

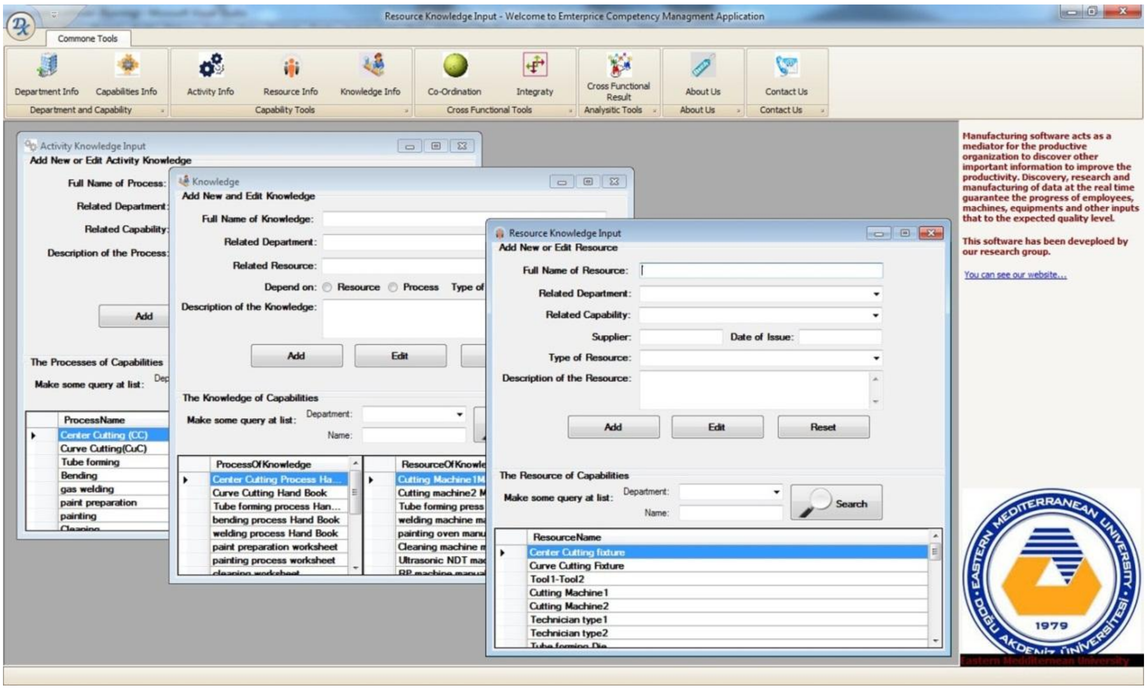


Figure 25-shot screen of the application for entering resource and activity information and knowledge for capability modeling purpose

<u>ICF Level:</u>

a) 'Cross-functional co-ordination' and 'Cross-functional integration' of capabilities

Three main sub-categories of enterprise competency exploitation are defined as (1) sector capability; (2) cross-functional co-ordination; and (3) cross-functional integration. The sector capability sub-category, concerns the store of enterprise competency aspects (i.e. resource, activity, and knowledge) which is resulted as a capability based knowledgebase. The 'cross-functional co-ordination' and 'cross-functional integration' sub-categories concerns the linking of enterprise competency aspects.

The 'Cross-functional co-ordination' process (definition 3) was adapted to all the identified capabilities at the sectors. For do this, the sector's capabilities sequence diagram (figure 20 and 21) is used. As examples:

Cross Functional co-ordination (CFC) $_{\text{Cutting}\rightarrow\text{Forming}}$:

Cross Functional co-ordination (CFC) $_{\text{Cutting}\rightarrow\text{Quality Control}}$:

Using the capabilities sequence diagram among the sectors (figure11), the 'Cross-functional integration' process (definition4) was adapted to the identified capabilities at the enterprise. As an example:

Cross Functional Integration (CFC) $_{\text{Detail Design}\rightarrow\text{Cutting}}$:

Figure26 illustrates the application which is developed for 'cross-functional co-ordination' and 'cross-functional integration' process, aiming to appreciate this processes using the knowledgebase and the sector's 'capabilities sequence diagrams' at the sector or the enterprise. The 'cross-functional co-ordination' and 'cross-functional integration' processes were separately adapted to each of the identified capabilities at the enterprise.

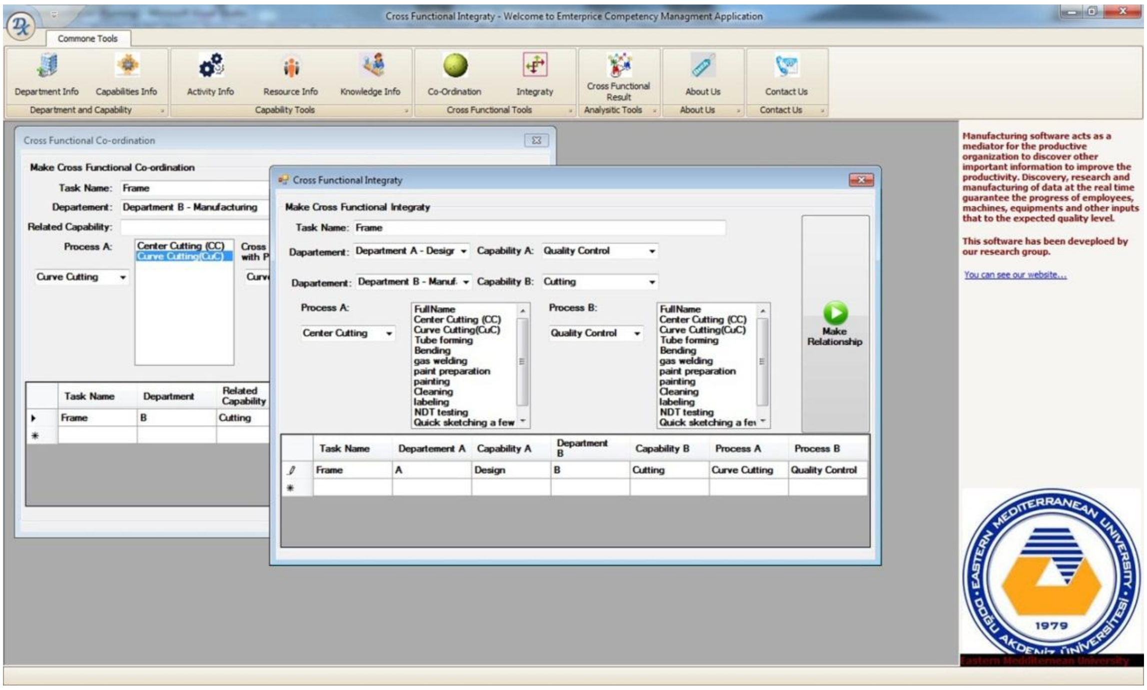


Figure 22-shot screen of the application for cross-function co-ordination and integration processes

b) Enterprise competency representation

At this stage all the competency aspects were stored, and all the competency associated sub-categories were linked as well; the next step is to represent enterprise competency. Using enterprise competency definition (definition 5) the example blow depicts competency creation process at the enterprise. For simplification in this example only three capabilities (detail design from sector A, and cutting and quality control from sector B) are taken in to consideration.

Competency $_{\text{(Cutting, Quality Control)}} \rightarrow$(Detail

Design):

Figure 27 depicts the dialog boxes in which the competency are shown. The dialog boxes also show the features of the competency stored in the knowledgebase. The experimental software developed can show capability attributes by clicking on the particular sign beside each row. For example, two existing activity instances can be observed: (a) curve cutting, and (b) Tube forming. For the curve cutting process there exist two boxes entitled as curve cutting record N1 and record N2. Within each boxes the interrelated activity which are resulted from cross-functional co-ordination process is listed. Furthermore, external related activity which results from cross-functional integration process and its desired capability is listed in another row. It is important to emphasize that by clicking on a capability at the boxes, the activity and resource information and the activity and resource knowledge will be displayed in separate dialog boxes. The developed prototype application and competency knowledgebase, captured, managed, and published the enterprise internal competency knowledge with a consisted set of concepts and aspects. The contents of competency knowledgebase is demonstrated in two formats human usage and machine readable (XML).This knowledgebase can be used to support various enterprise applications related to competences of an enterprise and, presents a clear understanding of the enterprise detail area of expertise.

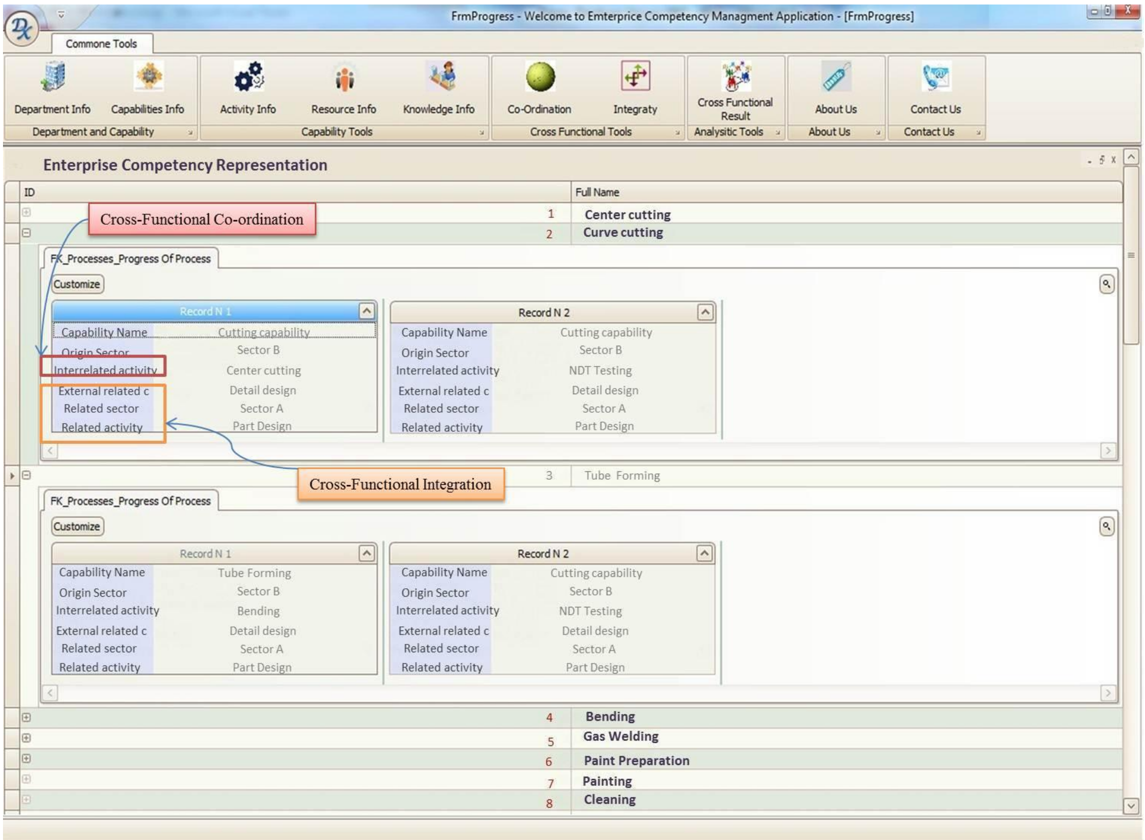


Figure 23-enterprise competency representation

Chapter 6

COMBINING RFID TECHNOLOGY WITH COMPETENCY-BASED ONTOLOGY TO DEVELOP AN INTELLIGENT MANUFACTURING SHOP

6.1 Overview

The aim of this chapter is to explore and investigate the idea of using RFID technology and proposed competency-based ontology in order to develop an intelligent distributed control system (IDCS) at a manufacturing facility. To this end, using competency-based ontology we will propose a new RFID-enabled integrated architecture for structural modelling of a manufacturing facility, to serve as a roadmap for redesigning an existing system to achieve higher performance, productivity, and flexibility, as well as lower costs. We will also describe our agent-based framework for implementing a redesigned IDCS at a given facility, based on smart processing of information carried by RFID tags.

6.2 Introduction

A typical manufacturing facility has a centralized database containing the product data model (PDM), which holds information on the product [81], and the manufacturing data model (MDM), which holds information on the systems needed to manufacture the product [45]. Together, the PDM and MDM provide an optimal scheduling plan for all control subsystems [44], organized hierarchically (i.e. as factories, cells, and stations) through a central host computer. This centralized control is quite effective when the product variety is low and the output volume is relatively stable, but does not adapt well to high-variety, low-volume production, or to ad-hoc situations requiring dynamic reconfiguration of subsystems [82].

Radio Frequency Identification (RFID) is an emerging technology appropriate to a wide range of applications. RFID tags offer several broad advantages, including long-distance contact, programmability, generous local storage, and non-line-of-sight scannability[40], and their resistance to magnetic interference, water damage, and high temperature make them very suitable for industrial applications [83]. In particular use of RFID tags in manufacturing systems enables collection and processing of real-time manufacturing and product information at all points of the value chain [84]. Replacing dedicated barcode on a centralized manufacturing control system with the RFID tags may be considered as an alternative for handling product complexity and process flexibility in a de-centralized way [85].

This chapter proposes architecture for structural modelling of an intelligent distributed control system for a manufacturing facility by utilizing RFID technology and competency-based ontology. Emphasis is placed on requirements analysis of the manufacturing system, design of RFID-enabled intelligent distributed control systems using Unified Modelling Language (UML) diagrams, and use of efficient algorithms and tools for implementation of these systems.

6.3 Flexible Manufacturing Systems and RFID Technology

RFID (Radio Frequency Identification) is a recent technology that uses radio waves to transfer data from a tag (typically attached to some object) to an antenna or reader. Tags can be classified as active, passive, and semi-passive. Radio frequency standard technology is similar to RFID reader in-terms of functionality, it can read data stored in the tag using antenna, then the data can be transferred to the computer and stored in a database also RFID reader can write real time state data of the RFID tag.

A flexible manufacturing system (FMS) is a manufacturing system capable of adapting, more or less promptly, to both predictable and unpredictable changes. The nature of this flexibility generally takes one of two forms: machine flexibility and routing flexibility [86]. Machine flexibility comprises a system's ability to produce new and different product types and to change the order of operations executed at a control node. Routing flexibility comprises a system's ability to use multiple machines to perform the same operation and to absorb large-scale changes in volume, capacity, capability, etc.

Although RFID technology has been extensively applied in the fields of logistics, supply chain optimization, warehousing, retailing, and transportation [87,88], it has only recently been introduced to the field of manufacturing systems. Nevertheless, this emerging field has already received considerable attention from researchers, who have recognized the great potential of RFID in providing component-specific data on operational status, and thereby making the production process less centralized and more flexible[82]. For example, Ruey-Shun Chen et al. (2010) [88] employed the RFID technology to "hook" the physical objects in an enterprise to business applications that are traditionally difficult to integrate. Wang et al [89] employed RFID technology to track object movement through a flexible manufacturing assembly line. [90] developed an RFID-assisted technology for automated identification, manipulation, and assembly of customized products in an experimental assembly line. [91] built an RFID-based real-time manufacturing information system to control the flow of information and materials across an entire manufacturing floor. [92] developed an RFID-based smart Kanban system for work-in progress (WIP) management.

RFID technology has also used to enhance the intelligence of control systems. For example, [93] combined mobile agents with RFID-based location sensing systems. [94] proposed the JADE framework (Java Agent Development Framework) for developing agent-based applications in compliance with FIPA (Foundation for Intelligent Physical Agents) specifications for interoperable intelligent multi-agent system. [95] proposed a method for making MAS compatible with existing Web Service standards. [96] described a flexible user- and service-oriented multi-agent architecture called FUSION.

The literatures surveyed by the authors indicate that, also existing working attempts are valuable for employing the RFID technology in a manufacturing system. However, there is no standard, empirical methodology for how a company should apply RFID technology to IDCS, given the unique complexities of most manufacturing systems. It has been suggested that unwieldy documentation, and a lack of a communication among the user, the system designer, and the implementer have been the major barriers to adopting new technology into existing systems [97]. Recognizing that structural and behavioral modeling has been the primary means for requirement analysis and redesign of manufacturing systems, we believe that it is a good starting point for developing an RFID-enabled IDCS, in that it creates a robust communication link between manufacturing system designers, users, and implementers. It should also provide a useful basis for evaluating designs, and translating them into operational applications.

6.4 Structural Modelling, Approaches and Tools

An important aspect of the design or redesign of a system is providing an abstract representation of system resources and activities for the design team [98]. A so-called structural model provides this representation. In the case of retrofitting, this structural model is used to capture the functionality of the existing system for the purpose of improving its performance, productivity, and/or cost-effectiveness [99].

The purpose of structural modeling is to produce a conceptual schema of entities and their relationships in order to (1) facilitate the process of communication among the system stockholders, (2) establish a common model that can accommodate the different needs of individuals and organizations within the enterprise, and (3) produce a logical model that can be implemented. In practice, two approaches to structural modeling have dominated: the procedural approach and the object-oriented approach. Both cover the same aspects of a system (i.e. processes, activities, and objects) and may employ a variety of existing tools, such as IDEF0, Data-flow diagrams (DFD), and Unified Modeling Language (UML).

We have chosen to use an object-oriented structural modeling approach based on UML. Under this approach, the modeled world is composed of basic elements or objects (e.g., the machines on a manufacturing floor) that tightly bind both data (attributes) and operations (methods) while hiding implementation details. The abstraction of objects with common characteristics forms a class, and an object is said to be an instance of this class. Systems are built via construction of objects and their relationships, revealing the inheritance, composition and associations between classes [100.101].

UML is a graphical modeling tool that enables system stockholders to design and reference object-oriented systems [102]. UML offers a way to visualize a system's architecture using different diagrams, including use case diagrams, class diagrams, activity diagrams, sequence diagrams, etc. For our purposes, UML holds several advantages over other paradigms and modeling languages: (1) UML has been successfully applied to a wide range of industrial applications[103]; (2) the software of most modern machines can be modeled with UML; (3) UML allows integration of techniques such as business modeling, object modeling, and component modeling; and (4) UML provides an information-rich representation that can be tested for consistency, analyzed, and translated into other representations.

6.5 Proposed Architecture for New Intelligent Distributed Control Systems

The proposed architecture is composed of a system requirements phase, a design and development phase, and an implementation phase, and each of these phases comprises a system level, a data level, and a sensor level. In the system requirement phase, the current system specification is captured holistically and problems that might be improved by RFID technology are identified. In the design and development phase, the manufacturing system is re-designed to address the problems identified in the system requirements phase. These results, at the system level, in a number of use cases, class diagrams, object diagrams, and sequence diagrams. At the data level, structural points are represented using cell activity and development diagrams. At the sensor level, the details of integrating RFID technology are captured through sequence, component, and class diagrams. A verification process ensures that the newly designed structure fulfills the requirements of the existing system. Ultimately, in the implementation phase, a hardware configuration and multi-agent framework are expressed at the system level, and interaction details are provided at the data and sensor levels.

This proposed architecture will be illustrated using a case study of a manufacturing facility composed of a single cell with three stations. This facility is physically located in the Flexible Manufacturing System (FMS) laboratory of Eastern Mediterranean University (EMU), and pictured in Figure 29.

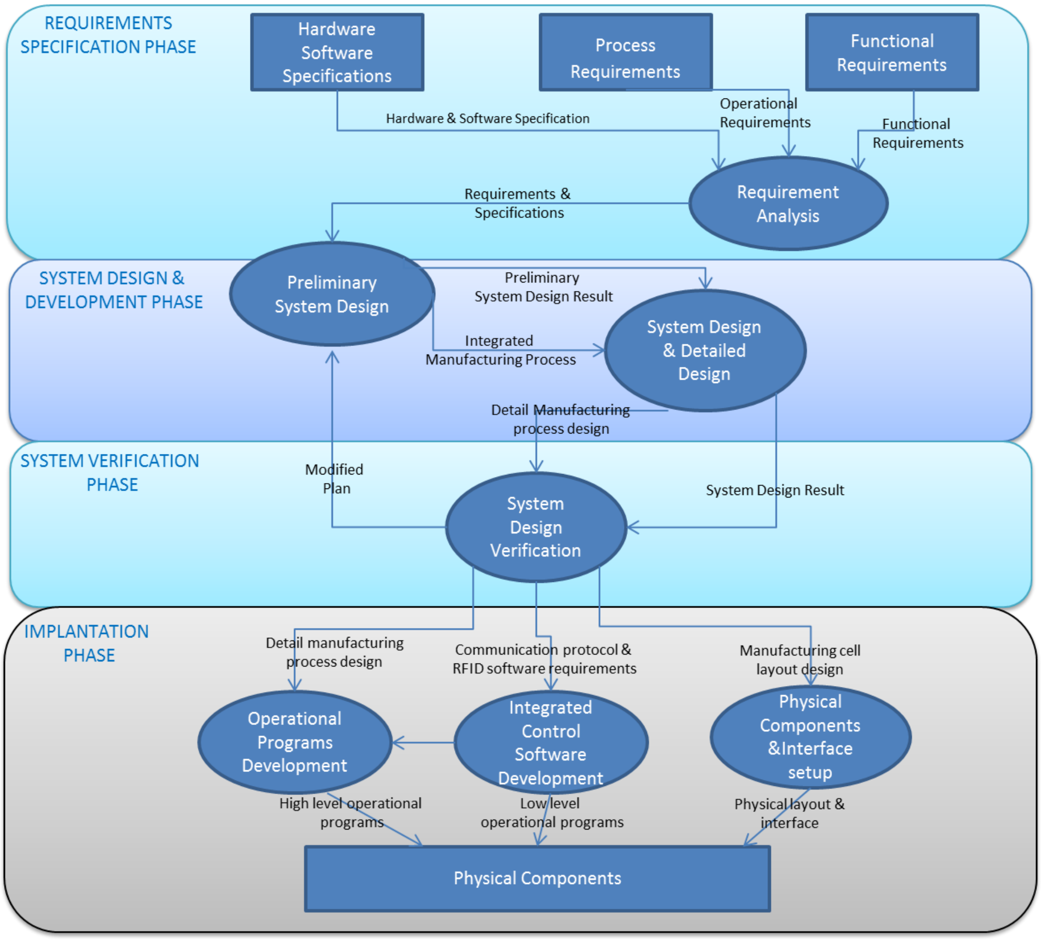


Figure 24-Proposed architecture for RFID-enabled FMS

Figure 25-FMS laboratory of Eastern Mediterranean University (EMU)

6.6 System Requirement Phase

The FMS laboratory at EMU was designed for education and research purposes. The laboratory consists of three stations. Station 1 is a machine tending station consisting of a CNC milling machine and a five-axis vertically articulated robot (SCORBOT - ER 9) designed for use in an industrial training facility. Station 2 is an assembly and quality control station containing one "SCORA ER 14" Robot (from Intelitek). This robot has a pneumatic gripper and works in connection with peripheral station devices, including a ball feeder, gluing machine, and laser-scan micrometer device (from Mitutoyo). Station 3 is an automatic storage and retrieval system (AS/RS) with 36 storage cells and a robot capable of articulating work pieces. A conveyer joins the three stations inside the cell.

The two robots are equipped with multi-tasking controllers, providing real-time control and synchronization of up to 12 axes of motion, 16 inputs, and 16 outputs, and supporting both stand-alone applications as well as sophisticated automated work cells. The overall system runs on a supervisory host control consisting of a set of Industrial Personal Computer (IPC) stations, a Programmable logical control (PLC) for controlling the conveyor, and a host computer that manages the cell orders using Open-CIM software (Figure 30).

Within the cell, barcode technology is used for identification of a part type with the appropriate machine (e.g., robot, CNC machine, etc.) and for tracing batches of components (i.e. all components with the same product operation list).

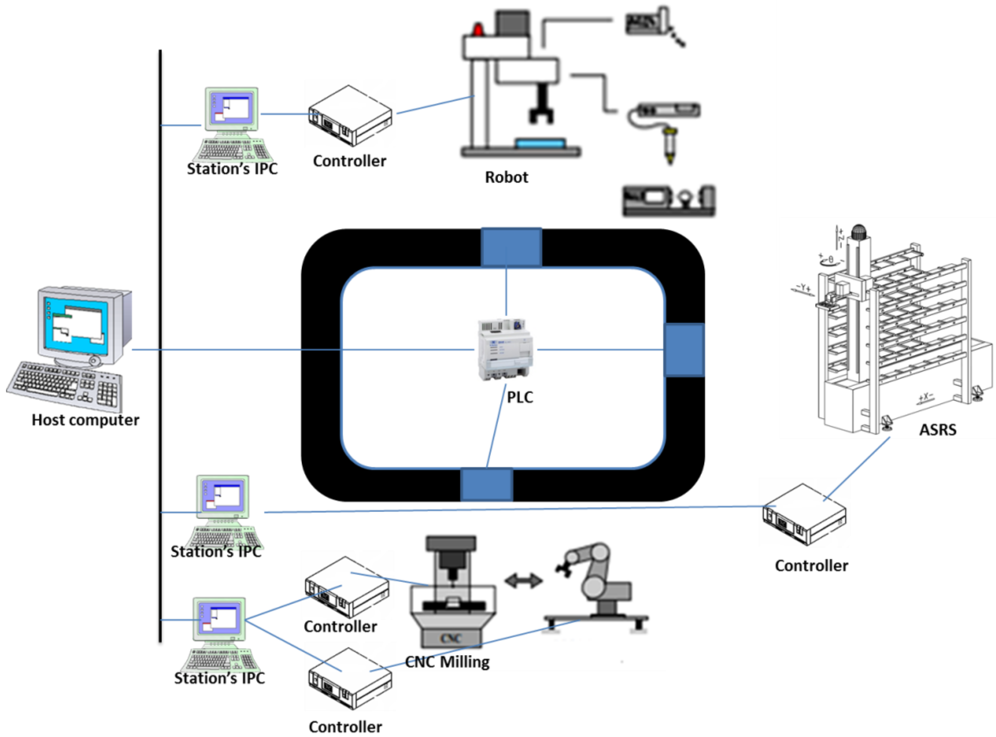


Figure 26- The Connections and Hierarchical Relationships Diagram of the FMS.

The problems with the current control architecture that might be improved by RFID technology are as follow:

- The manufacturing system is controlled by a centralized architecture running on a single host computer, from which all control decisions are issued.
- The stations have no autonomous control unit for their operations.

- The barcode technology cannot provide real-time information on component presence/position or on production progress, and is not suited to tracking new products one-by-one.
- The system cannot be reconfigured in real-time.

Development of an RFID-enabled IDCS to address these problems is justified as follows:

- When a part is complex, it may lack a convenient and scannable location for bar codes. RFID tags can be placed anywhere on the part, and scanned from any orientation.
- Unlike bar codes, RFID tags can store data for continuous production updates.
- Unlike bar codes, RFID tags are unaffected by the dust and grime common to industrial environments.
- RFID tags can provide monitoring of the arrival, continuous presence, and departure of specific parts to/from a cell, allowing for better management of routes and locations in the assembly environment.

6.7 Design and Development Phase

6.7.1 System level

A use case diagram is an appropriate tool for working connections among the users and stakeholders of a system, and for demonstrating the structure and behavior of entities at the highest level of abstraction. Figure 30 shows schematically how the operator of the system can interact with the Human Machine Interface . The upper rectangle of figure 32 contains the two use cases for HMI: monitoring and controlling.

The link between this HMI rectangle and the operator indicates that the operator is charged with controlling and monitoring the system. Machining, Assembling, and ASRS are the main use cases of the overall system, as represented by the lower rectangles, which are connected to the HMI rectangle by specialization arrows. These rectangles contain further specializations of their use cases. For instance, the ASRS use case contains action for processing, storing, moving, and sensing.

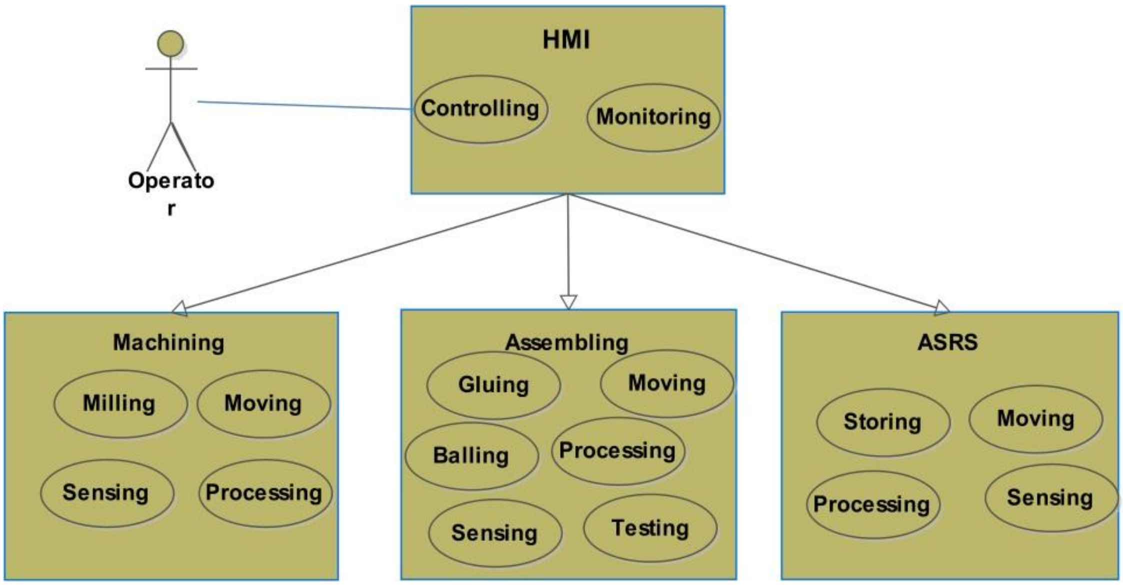


Figure 27- Shop Human Machine Interface

A class diagram is a static view of the system and its object orientation. Figure 33 depicts the main modules of the target system and their interconnections. The top part of this diagram shows the hierarchical model of a manufacturing facility, or “Shop”. A shop can encapsulate a number of cells, each of which may contain several stations.

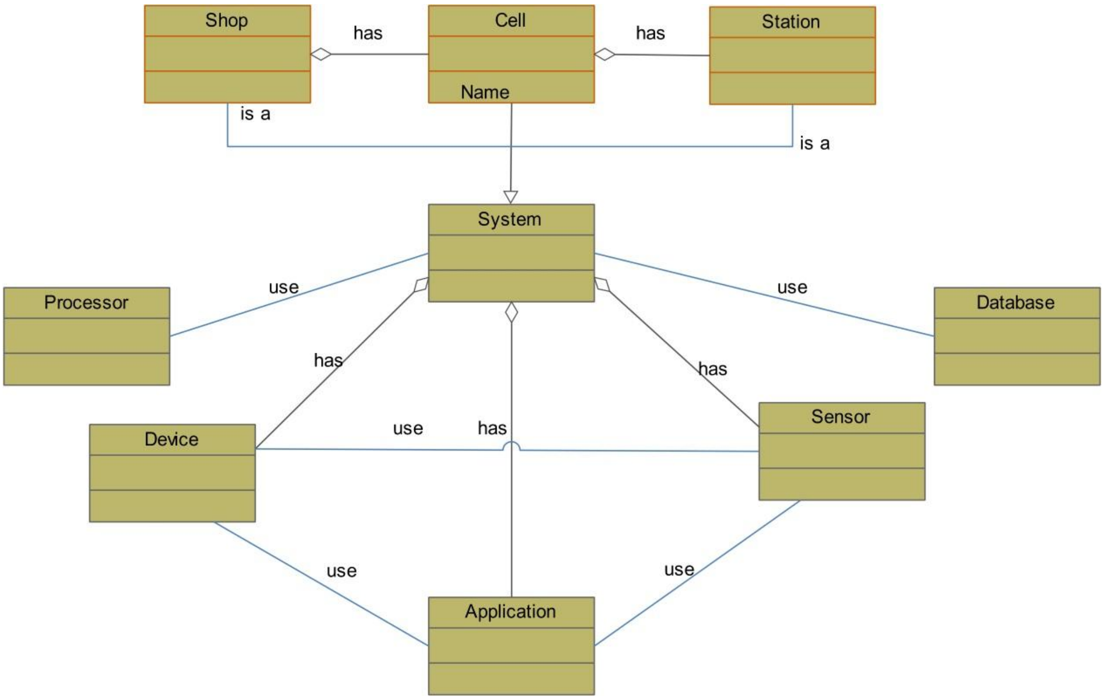


Figure 28- Generic class diagram for target manufacturing system (MS)

A UML object diagram demonstrates static aspects of the system's building blocks. In our target system, a station contains several resources representing mechanical and electrical components, connected by means of an IPC. All the stations in the shop form a network, which is then connected to the HMI. Figure 34 shows an object diagram for assembling stations.

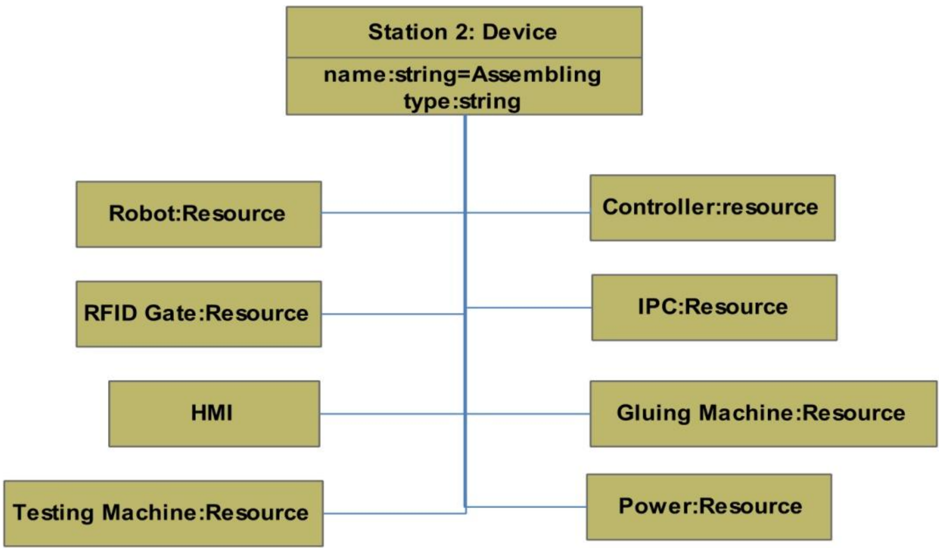


Figure 29- Assembling station's UML object diagram

A station contains several devices, applications, and an RFID-gate, which integrates with an IPC and connects to a data bus. The station's UML sequence diagram will help system analyzers and developers understand the dynamic behaviors of stations. A station receives messages from a part's tag and performs services accordingly. The station's RFID-gate then reads the same message and, based on its content, permits subsequent operations. Several operations based on the scenario can be executed in the machining, assembling as well as AS/RS stations. A sample operation for the assembling station is illustrated in Figure 35.

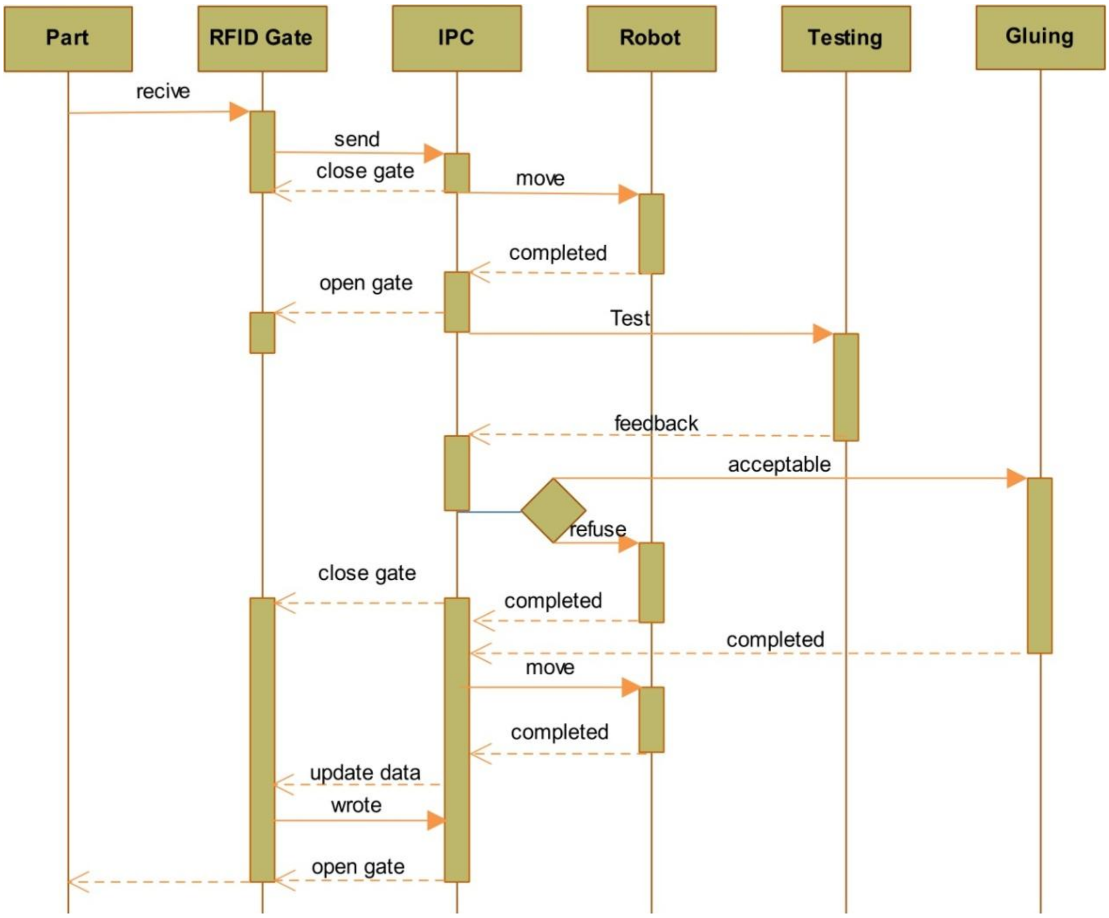


Figure 30- Assembling station's UML sequence diagram

6.7.2 Data level

The data level presents the data flow and data connections among cell components. These may be expressed through structural and/or behavioral diagrams. Specifically, structural modeling is depicted through activity diagrams of the cells, while behavioral modeling is represented through development diagrams of the cells.

The UML activity diagram of the cell (figure 36) provides a clear graphical schematic for implementation, as well as verification parameters.

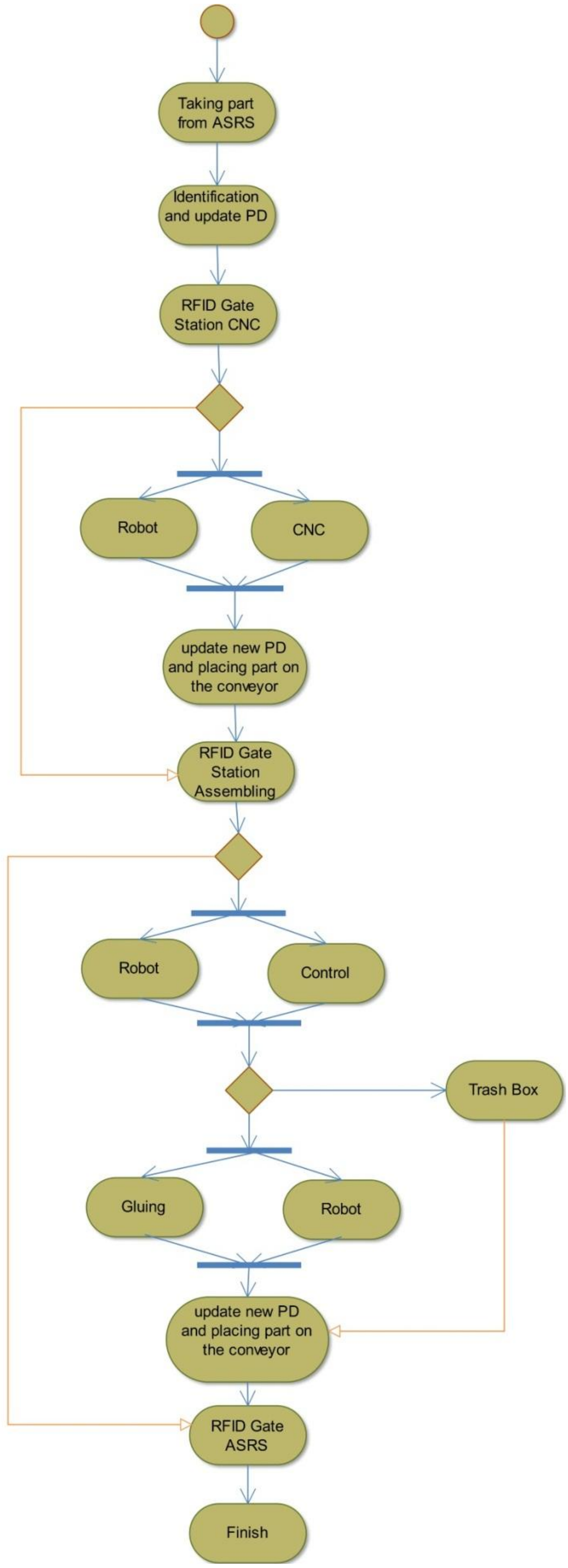


Figure 31- Cell UML activity diagram

This diagram is divided into three layers: machining, assembly, and AS/RS. In each of these layers, an RFID-gate containing two antennas is integrated with a reader. The product development chain starts with a request from HMI to AS/RS. In response, AS/RS provides a part (in this case, raw material) to the conveyer. The RFID tag attached to this part stores lifecycle information for the production system and is updated by the RFID-gates. This information includes, but is not limited to: universal identification number, parts number, station identification, processed status for a station, delivery deadline, and order number. The RFID-gate of the machining station reads the part information and instructs the station's robot to pick up the part up and place it at the appropriate position. The RFID-gate also sends process-related information to the station IPC to request a machine controller for the machining process. When this process is finished, the robot takes the part from the machine and puts it on the conveyor. As the part passes through the station RFID-gate, its information (i.e. processed status) is updated. This cycle is repeated at subsequent stations until the product is finished and placed at a suitable position in the AS/RS.

A UML deployment diagram provides an implementation view of the stations. Figure 35 is a deployment diagram for a cell. Note that each station consists of several components, connected via a wireless communication link. Information on a given part is shared among the stations of the cell before it is forwarded to the HMI.

The HMI can process as well as transmit/receive, and can therefore be connected directly to the Internet for remote control via TCP/IP.

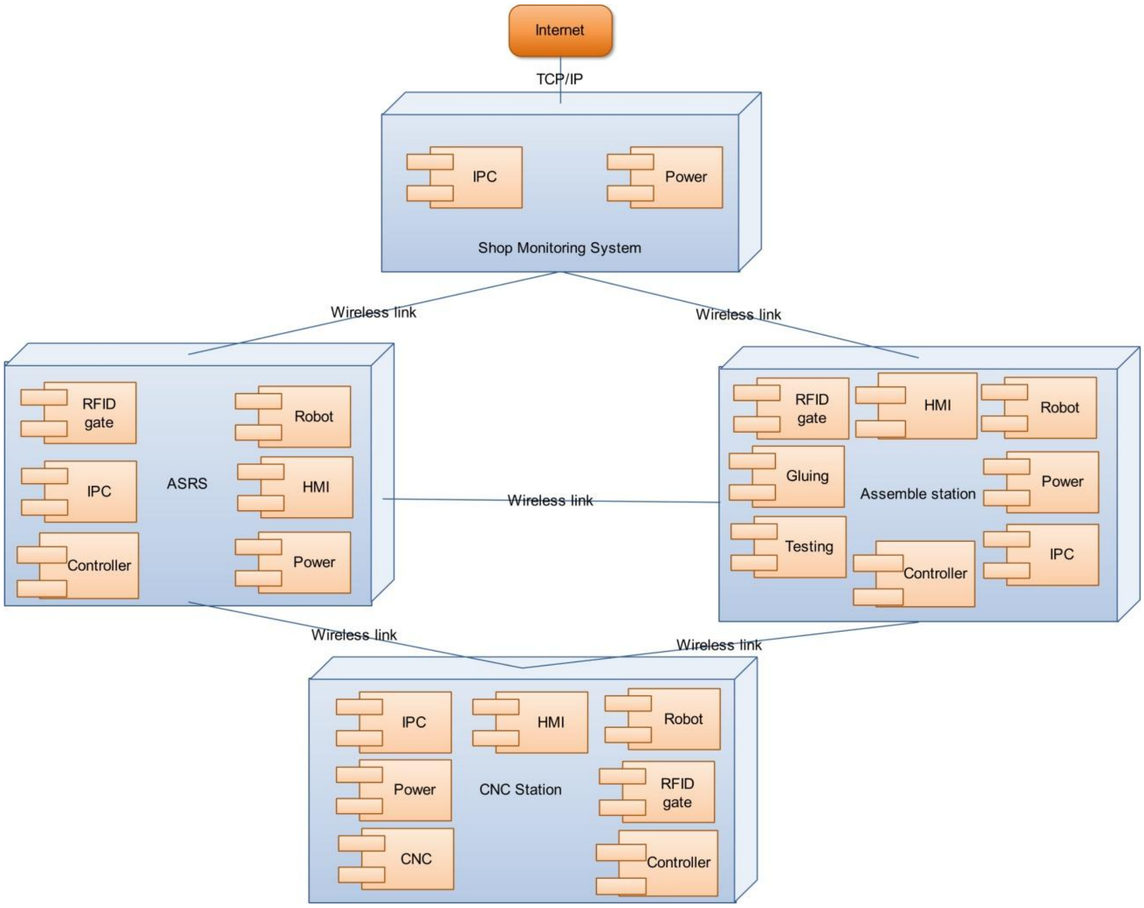


Figure 32- UML deployment diagram of the cell

6.7.3 Sensor level

Integrating RFID technology in a manufacturing system enables real-time information about products in the value chain. This information can be used to improve system productivity, agility, and flexibility. It is also vital for real-time reconfiguration, since local information storage allows for a more decentralized production system.

Schematically, an RFID system is composed of a tag, an antenna, and a reader. Data is stored on the tag, read or written by the antenna, and sent to the reader, which decodes and forwards it elsewhere in the system (figure 38).

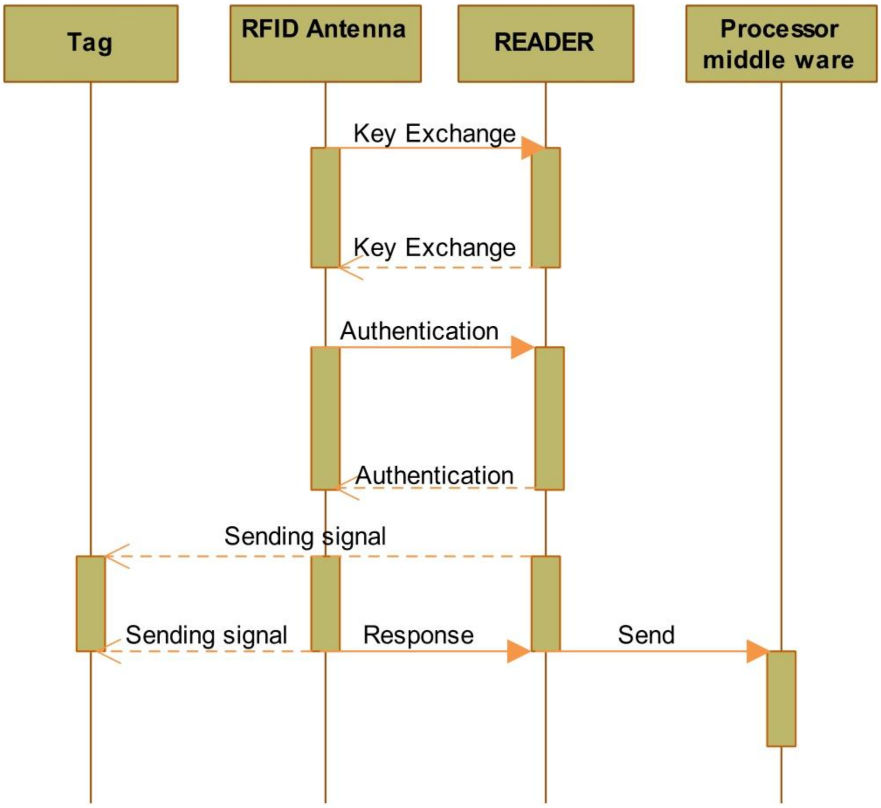


Figure 33- Relationship between RFID antenna and the reader

In the proposed manufacturing cell, the station's RFID-gate is used not only for scanning parts but also for updating tag information and loading/unloading stations. Parts are delivered to stations according to their next stations ID. Each station receives parts from its RFID-gate. The station IPC then performs some operations on the part before placing it back on the conveyor. The component diagram for an RFID-gate is illustrated in figure 39.

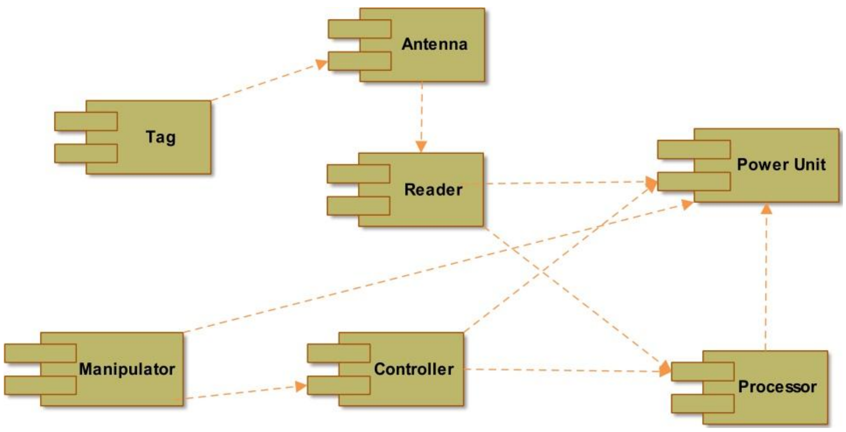


Figure 34- RFID-gate components diagram

The part tag allows the RFID-gate to switch and route mutually connected conveyors automatically, so that part is transported to the desired station.

6.8 Verification Process

The verification block compares data generated during the system requirement phase to data generated during the design and development phase to determine whether the designed model meets the problem definition. The Extensible Markup Language (XML) is used to encode exchanged information (see figure 40). The data file generated at the system requirement phase consists of three groups of information [27,28]:

1. Supporting data structures: (a) measurement units (time units); (b) statistics (standard deviations, average, state time, and running time); (c) model references (model name, user, date, and time).
2. Manufacturing data structures: (a) element name; (b) element class; (c) resources (machines, laborers, etc.); (d) operations lists; (e) events lists; (f) element failures; (g) daily schedules; (h) element busy time; (i) element idle time.

3. Objects negotiation data structures: (a) message name; (b) start message element; (c) end message element; (d) start messaging time; (e) end messaging time.

As models are processed during the design and development phase, their UML diagrams are transformed into new data files. After the consistency rules have been applied to these files, a matching environment that captures differences between two data files is ready to perform verification.

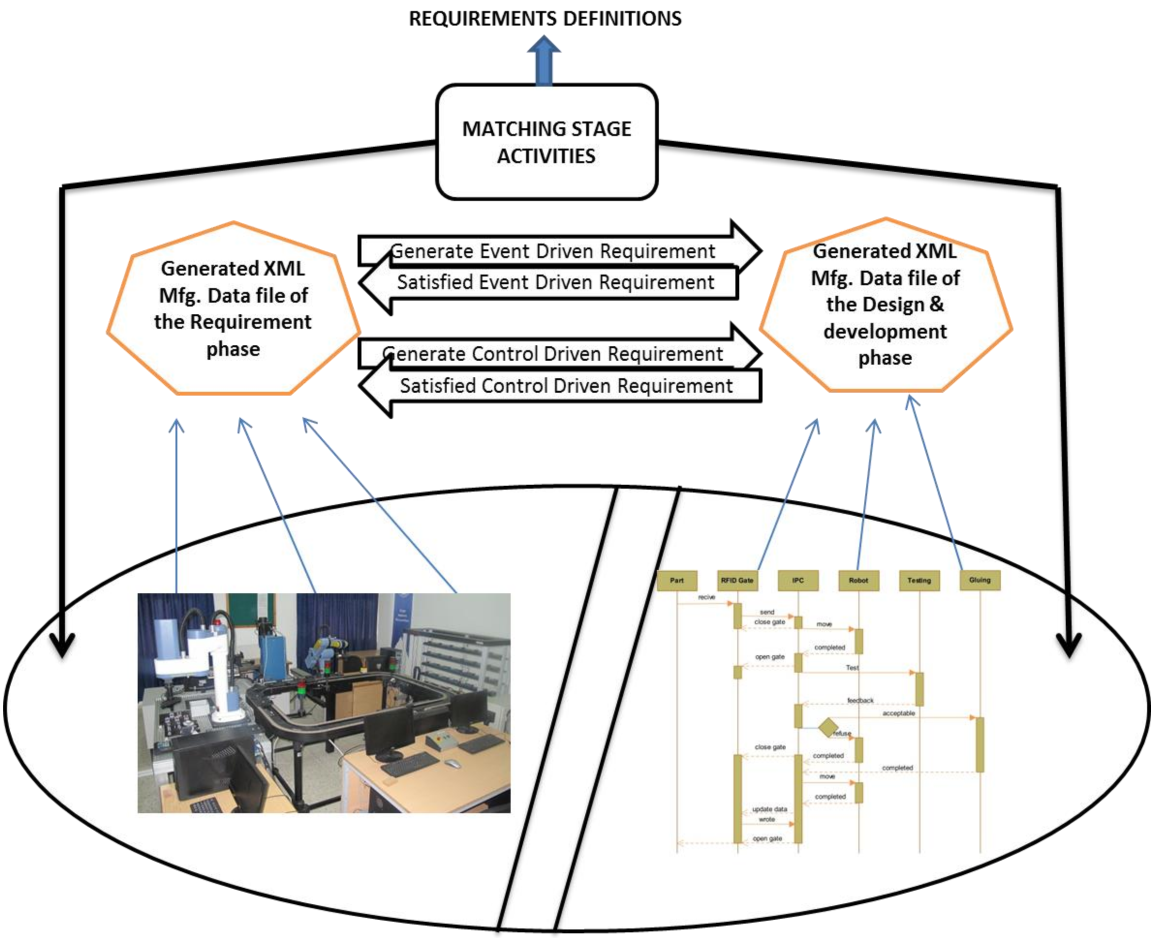


Figure 35- Verification environment

6.9 Implementation Phase

The major concerns during the implementation phase are software and ICT development for the purposes of (a) controlling stations, (b) monitoring the real-time state of products at stations and cells, (c) storing data, (d) communicating and transforming data from readers to station IPC's, and (e) defining a new part operation list.

The agent concepts offer a new approach for implementing diverse autonomous applications. A multi-agent system consists of a number of agents that work together to find answers to problems that are beyond the individual capabilities or knowledge of each entity. These agents interact with one another, typically by exchanging messages through the computer network framework [104,105].

6.9. 1Multi-agent system framework

Our RFID-enabled IDCS is designed as a network of software agents that interact with each other and with system actors. These agents include the Shop Management Agent, Agent Manager, Shop Monitoring and Command Agent, Station Control Agents, Station Monitoring Agents, Agent Machine Interface and Manufacturing Resource Agent. The framework also includes a shop database and station database, and a knowledge model for inter-agent communication [48]. The framework integrates all software agents with these databases and the knowledge model, as illustrated in figure 41.

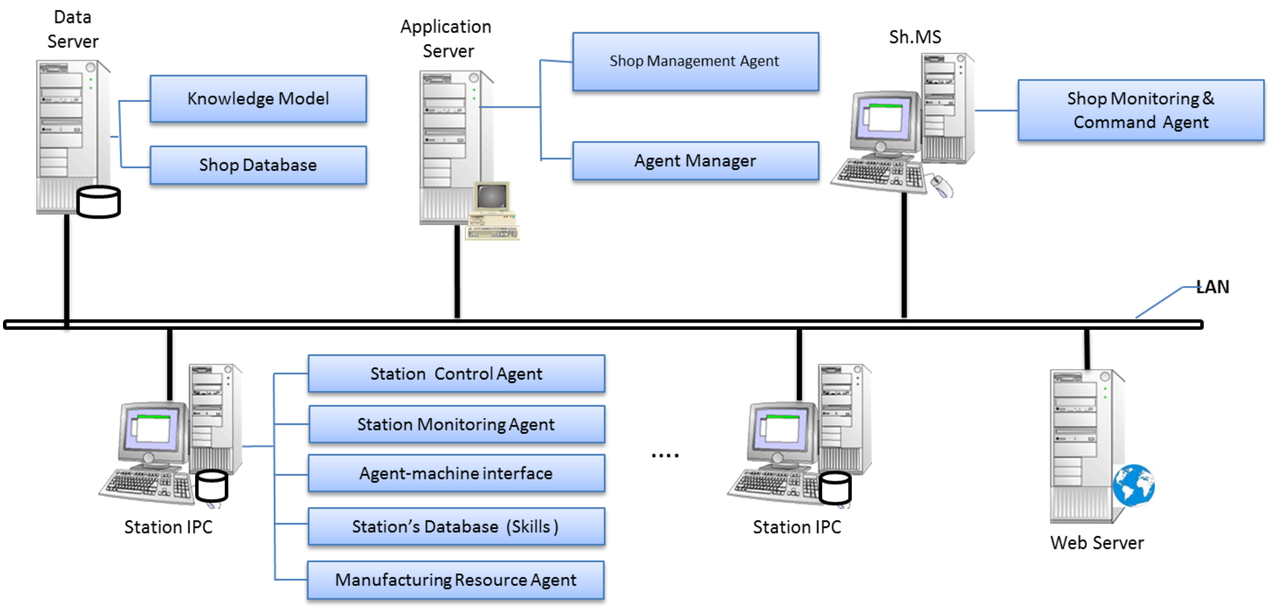


Figure 36- Multi-agent system framework

The functionality of the main software agents in the proposed multi-agent system are as follows:

Shop Management Agent is responsible for helping a shop manager define a new product for the system, specify initial manufacturing parameters, and decompose product operation for the system. It has a user interface for assisting the shop manager in making necessary changes as the plan gets more detailed.

Agent Manager is responsible for controlling the availability and use of all agents by maintaining an accurate, representation of their activities and a means of inter-agent communication.

Shop Monitoring and Command Agent (SMCA) is responsible for obtaining and displaying the real-time state of raw materials, in-process products, and finished products as well as the status of stations. It also serves as a port for incoming manual commands from the shop supervisor.

Station Control Agent selects suitable capabilities from the product operation list for a station, and requests capabilities from basic agents to perform a job. May update state data at the station's database, and send control instructions to the shop database.

Station Monitoring Agent tracks the manufacturing state of a station and stores state history at the station database.

Manufacturing Resource Agent represents specific manufacturing components (e.g., robots, conveyors, machinery, etc.) as encapsulations of the capabilities, interaction behaviors (i.e. collective capabilities), and internal status that characterize those components.

Agent-Machine Interface acts as a kind of device driver to the MRA. For each different controller there should be one agent machine interface.

All agents are connected by a local network through which they communicate with on another via asynchronous message passing. To keep SMCA performance high, the SMA and AM run on an application server, the knowledge model operates on the data server responsible for maintaining the shop database, and the SCA, SMA, MRA, and AMI, along with the station's database, operate on the station's IPC.

6.9.2 Competency-based ontology

For proper communication between the agents in multi-agent system ontology have to be defined [104]. It has to mention that the defined ontology for the current work is more a knowledge model than a real ontology. However, the term ontology is used by most multi-agent environments and, therefore, it will also be used here [105]. Capabilities refer to the company's ability to use its resources. In that, capability is a chain of business processes and routines which manage the interaction between its resources. In the proposed capability-based ontology, the capabilities within the production system is identified and the relationships of the main elements of the capability namely resource, process and knowledge are established. In current work the author's definition for capability is:

Manufacturing capability can be described as a set of information embedded by all available resources and corresponding processes that could be performed by those resources, as well as the knowledge about how these resources and processes can be effectively, efficiently and economically used. Fig 42 illustrates a generic manufacturing capability model in the top-level diagram.

Manufacturing capability model composed of all the main classes and their relationships promotes the realization of a single conceptual capability model. In manufacturing capability model, a facility comprises of one or many resources, processes and knowledge. Among these, there exist associated relationships. The key role of the associations between classes shows that resources perform processes, and knowledge constraints of one another that are both resources and processes. Any event of a process is related to one or many instances of the resources features that specify the pre-condition and post-condition of that particular process. Any resource feature can be achieved by one or multiple different processes. Knowledge is partially imposed upon the use of resources and processes.

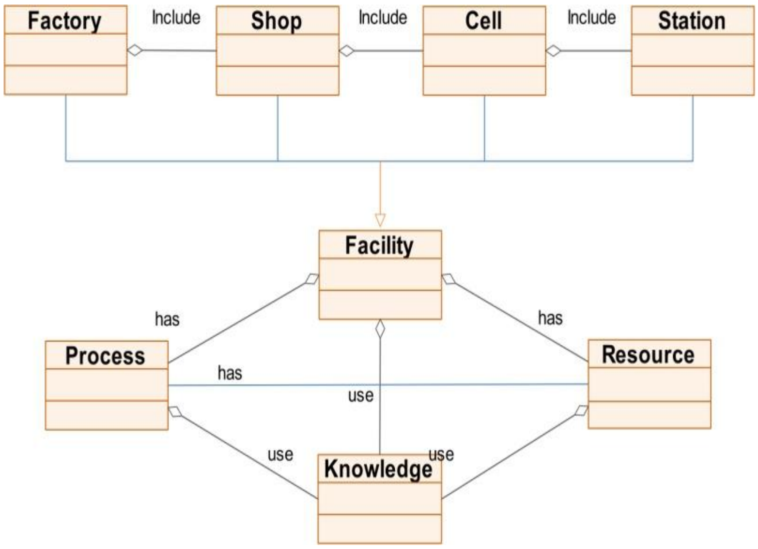


Figure 37- Manufacturing capability general model (Adapted from [30])

The main elements of the manufacturing capability model is decomposed and sub-modeled for the desired flexible manufacturing system at shop and station level for generating knowledge model.

Figure 43 illustrates the resource modeling of the shop using logical UML object diagram. UML object diagrams are used to render a set of objects and their relationships. The purpose of using the object diagram can be summarized as "forward and reverse engineering" object relationships of a system, static view of an interaction, understanding object behavior and their relationships from practical perspectives. The object diagram of the shop involves the machining, assembling and AS/RS stations which realizes the added value processes utilizing the station's resources. The material flows between the stations and are completed using a conveyer. Each of the stations involves several resources, the material flow between the station's resources are realized by station's robot. Similar to the shop level the data flow at stations level is integrated by station's IPC.

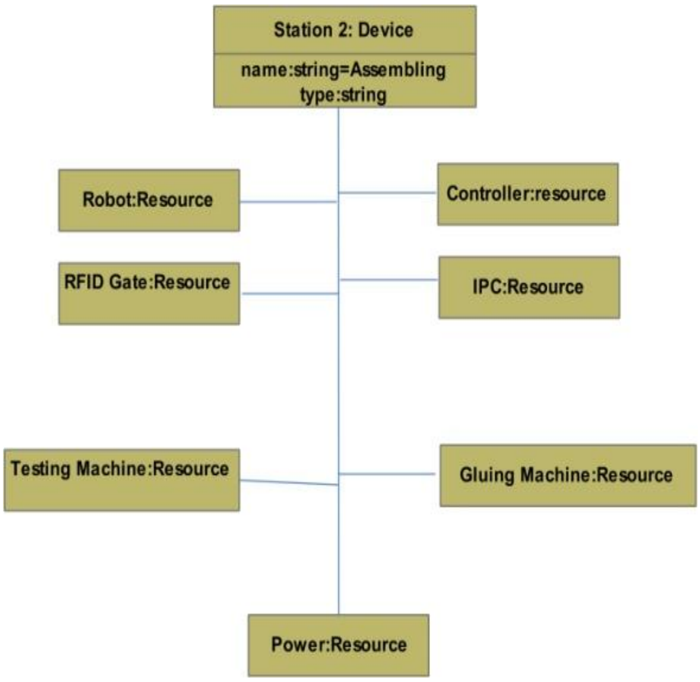


Figure 38- Object diagram of the shop

UML activity and sequence diagrams are outlined for representing the manufacturing processes of the shop and stations. The activity diagram is used for graphical representation of work flow of the system, which is backing up for selection, repetition and concurrency. An activity diagram consists of many shapes, connected with arrows. The most important shapes in use here are; oval, diamond, bar, filled circle and encircle filled circle. The oval represents a process, while the diamond represents a decision, the bars represents the starting or ending of simultaneous processes, the filled circle states the starting process while encircle filled circle the ending of the process. All this can be seen in Figure 44 where all the steps and processes for the shop are clearly shown and demonstrated.

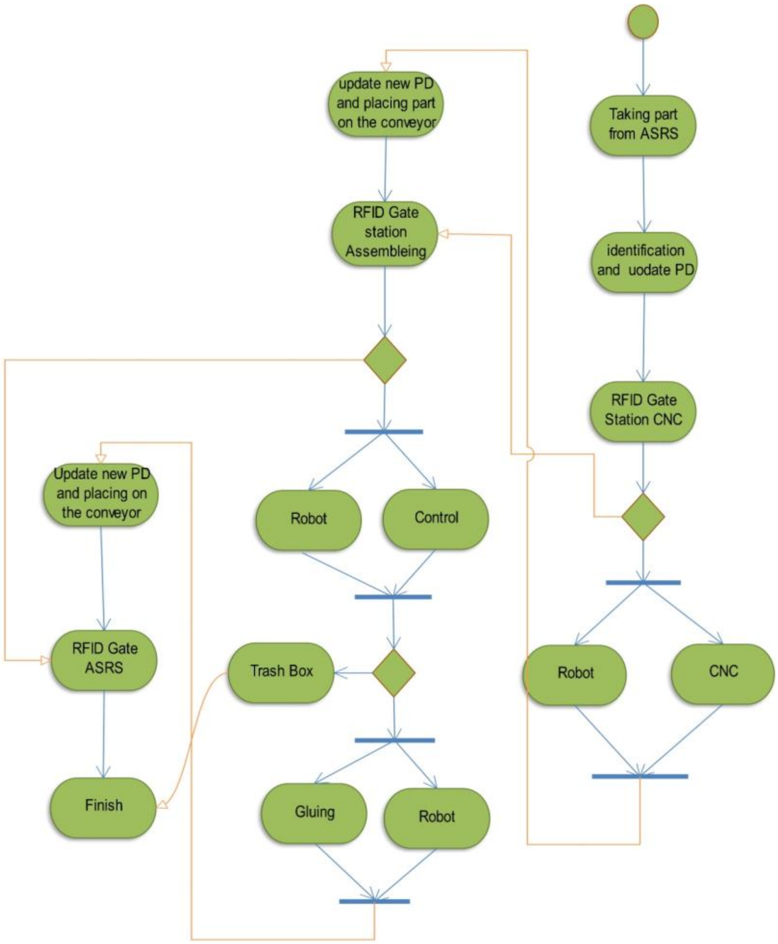


Figure 39- Shop's Activate Diagram

Sequence diagram is a type of dynamic work flow diagram which shows how processes work together and what the demand is. It is a creative plan as well as a message on how to work on the system telling the sequence to follow. The sequence diagram describes the levels of communication in the system. It represents the activities and processes related to each scenario followed by the sequence of messages to be performed on each scenario depending on their need or specification. The sequence diagram of the shop is represented in Figure 45. These rectangles illustrate a manufacturing process and each of the columns demonstrates a manufacturing activity. Depend on the sequence of the processes, arrows connect the processes, the processing duration is bolted on the column based on the duration.

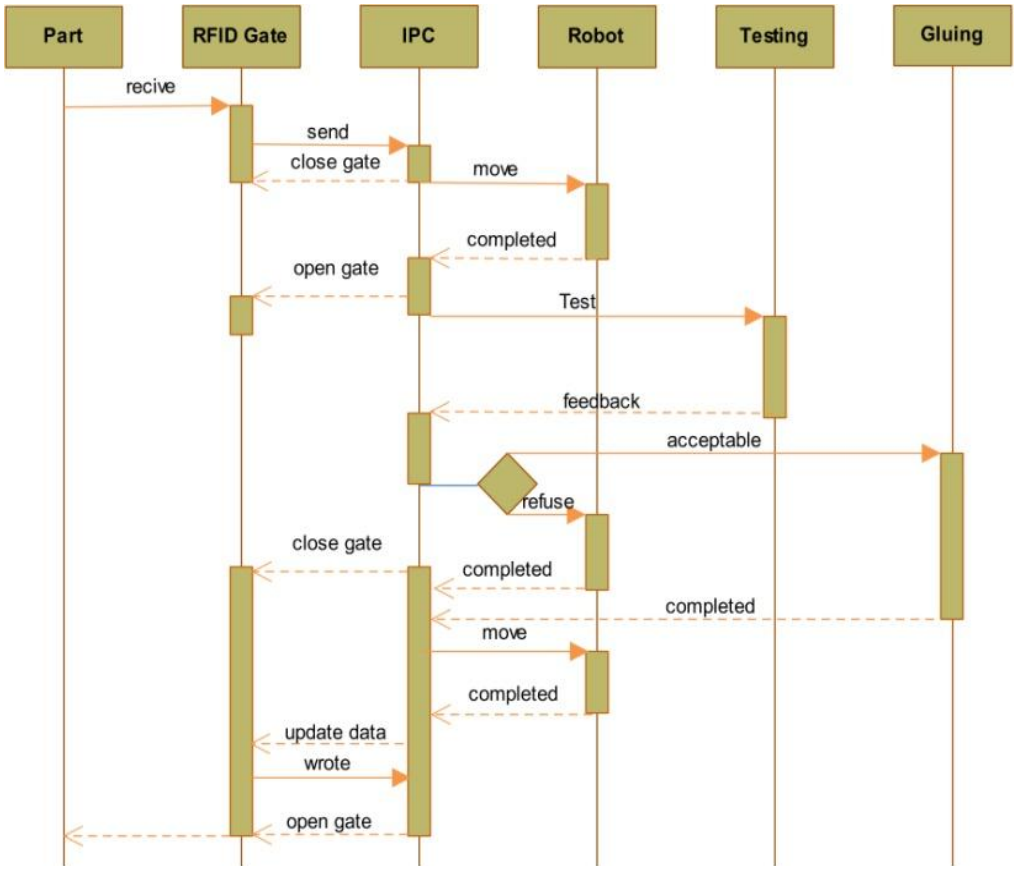


Figure 40- Shop Sequence Diagram

Manufacturing knowledge is an important part of the intended capability-based ontology since it contains all the processes and resources knowledge identified in the manufacturing shop. Therefore, it is necessary to follow a structure that allows the access and storage of the wide range of manufacturing knowledge. To define these, knowledge structures is necessary to explain what process and resource knowledge the manufacturing facility has and how they can be represented. Some examples of collected knowledge are presented to clarify the definitions of knowledge representation used in this work. Graphs, texts, tables, diagrams, formulas are some of the examples for explicit knowledge. While pattern, storytelling, video-clips and sketches are instances for tacit knowledge and implicit knowledge is concluded from performance of a person. Knowledge related to manufacturing processes and manufacturing resources are structured using different types of knowledge namely:

explicit process knowledge, tacit process knowledge, implicit process knowledge, explicit resource knowledge, tacit resource knowledge and, implicit resource knowledge.

As it is shown on Figure 40 the manufacturing knowledge class is depicted by a superclass redefined to organize separate types of knowledge and using this knowledge to access the facility knowledge. A superclass named types of knowledge is defined to organize the current knowledge types in a manufacturing facility. Explicit, tacit and implicit knowledge are considered subclasses of this superclass. The explicit knowledge described is divided into table, graph and procedure subclasses. In a similar manner, the tacit knowledge can be divided into sketch, pattern, video clip and storytelling. Implicit knowledge is considered in the implicit knowledge class. Figure 46 shows an explicit, tacit, implicit type of knowledge structure to represent facility another main class entitled as Types of knowledge.

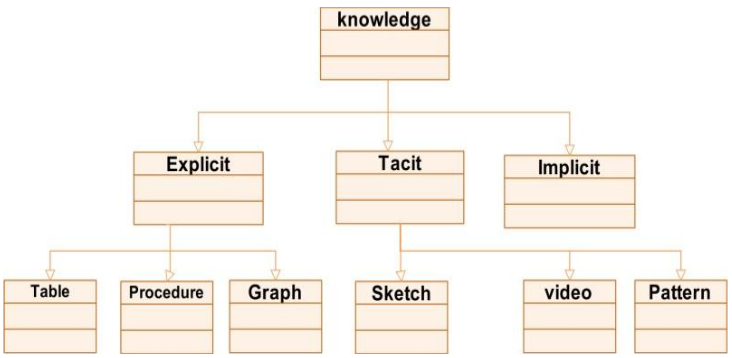


Figure 41- Explicit, tacit and implicit types of knowledge structure

6.9.3 Station Control Agent [58]

As a base component of the proposed multi-agent framework for RFID-enabled IDCS, station control must be formally specified, implemented, integrated, and tested. Figure 47 illustrates the architecture of the SCA and its interactions with AMI and other engineering tools and agents. The SCA is a kind of semiautonomous and service-oriented agent that activates when a tag (part) passes through the station's RFID-gate. Details of this process are as follow:

Step 1: Each tag holds the product operation list written to the active tag at AS/RS's RFID-gate, based on information from the shop database.

Step 2: The product operation list is loaded into the SCA from the RFID-gate. The SCA receives this information through the "Reader Middleware Agent" and sends it to the "complex skill" unit.

Step 3: The "complex skill" unit verifies the received product operation list against the capabilities available on the station, and decides whether further action is appropriate.

Step 4: If the part is served by a given station, the "Complex Skill" unit will select the appropriate capabilities from its product operation list.

Step 5: The "Complex skill" unit, with the assistance of the knowledge model for each operation, assigns the information related to manufacturing resources and processes as well as the strategy about effectively and efficiently use of these resources and processes.

Step 6: The "Control System" unit requests relevant services from the MRAs, if the MRAs accept these requests, the "Control System" unit stores the appropriate manufacturing resource information on the station database.

Step 7: the “Control System” unit sends the command for a specific job through the AMIs to the MRAs (e.g., telling a station’s robot to take the component from the conveyer, place it on the CNC milling machine table for processing there).

Step 8: As soon as the job starts at a station, the MRAs sends feedback to the “Control System” unit through the AMIs. Once the “Control System” unit receives feedback from the manufacturing resources controllers, it sends it to the SMA to update manufacturing process state in the station database.

Step 9: When the manufacturing process for the component is finished, the SMA sends the history of the component state to the shop database.

In case of any constraint conflicts on the station, the station controller returns relevant feedback to the SCA to support further decisions and re-configurations. The SCA maintains a real-time data exchange with other agents as well as with certain tools (e.g. the shop database) in the system.

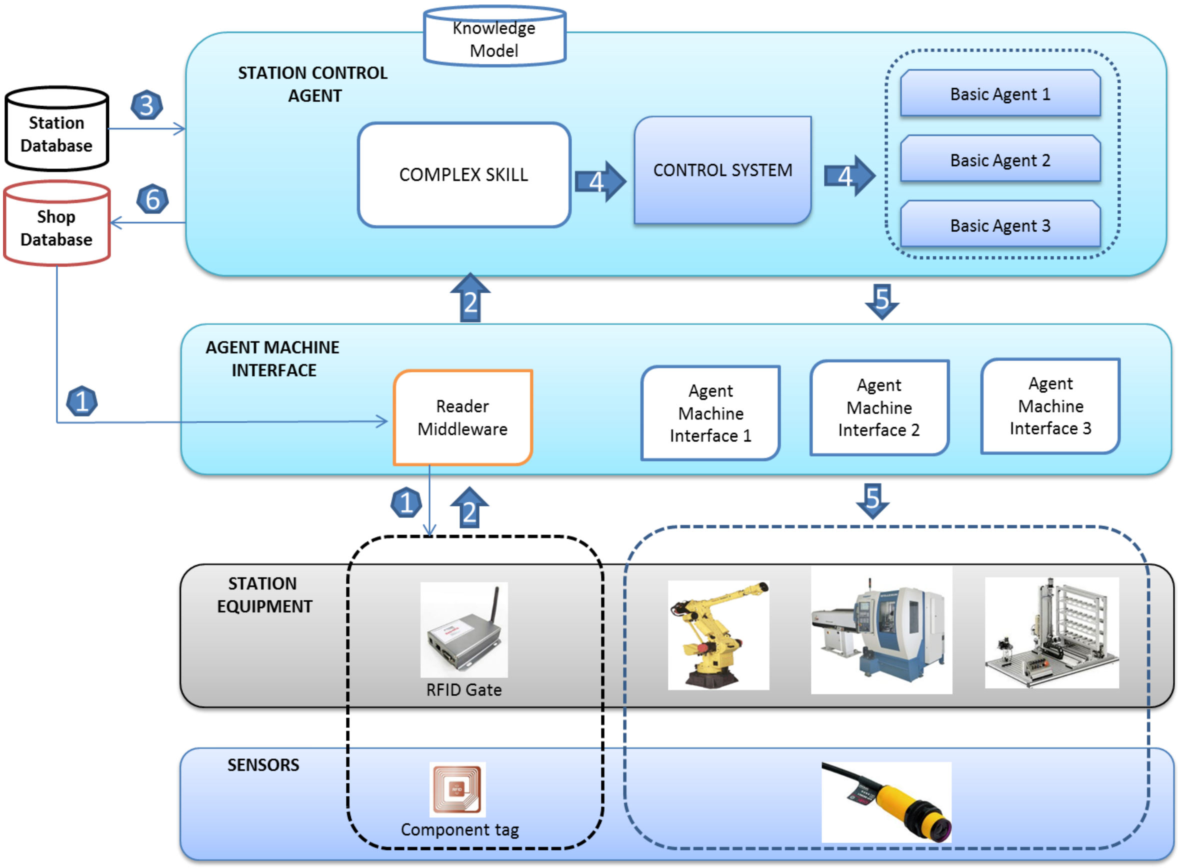


Figure 42- Station Control Agent" and its interactions with other agents in the system

6.9.4 Manufacturing Resource Agent [59]

The MRA represents specific manufacturing components (e.g., robots, conveyors, CNC machines, etc.) by encapsulating all of the operations, interaction behaviors, and internal status necessary to describe these physical components. When asked to execute one of its published operations (by a controller agent or another MRA), the MRA issues the necessary commands to the AMI connected to its physical controller. The MRA architecture is represented in Figure 48. Note that it is a generic agent in the sense that no new code is necessary to create different MRAs. They only differ in capabilities and configuration.

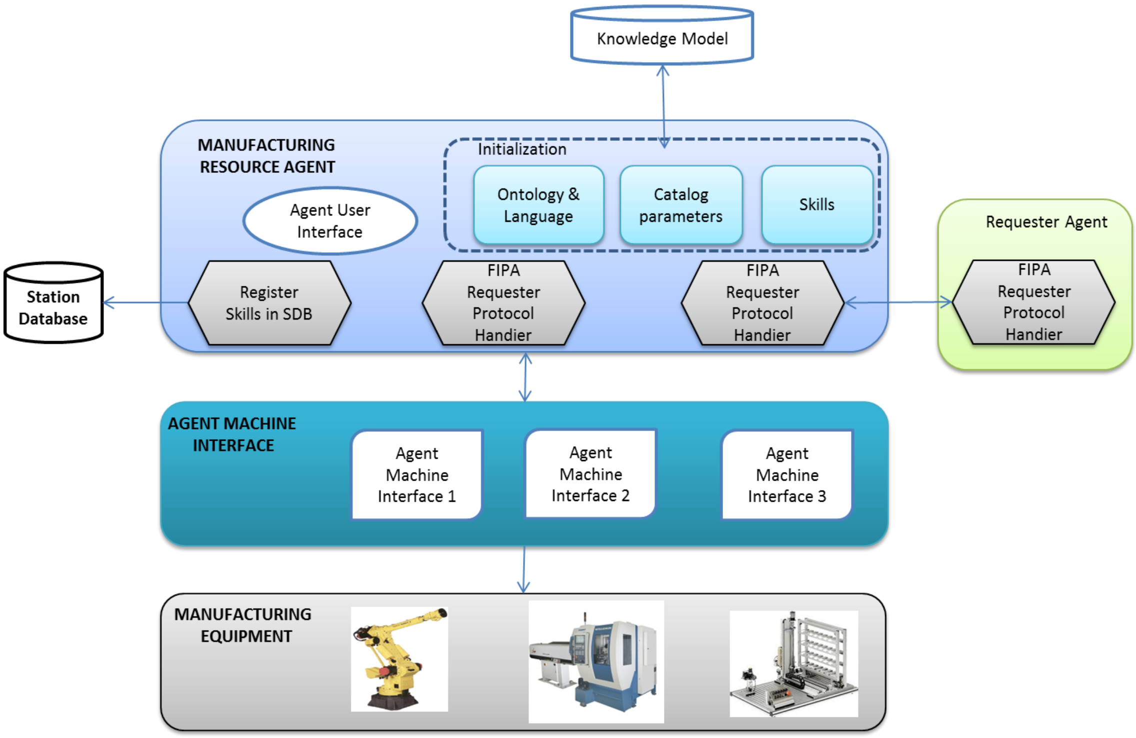


Figure 43- Manufacturing Resource Agent

6.9.5 Hardware configuration

Based on the multi-agent framework for RFID-enabled IDCS proposed in Section 9.1, we propose the hardware architecture depicted in figure 49. This includes all station resources (e.g. CNC milling machine, robot, etc), station controllers, and station IPC's. The new components to be added to the EMU-FMS lab are as follow:

- 20 RFID Active tags (FS1001T active RFID tags). Each tag is attached to a part.
- An RFID-gate for each station, including (RFID-gate is illustrated at figure 48)
    a) Motorola's AN480 antenna, installed on the front of each station
    b) Motorola FX7400 RFID reader, installed near the station's IPC

c) A Manipulator for loading/unloading parts at the stations.

- 3 IPC's*
- A PC for the Shop Monitoring and Command Agent*
- An application server*
- A data server*
- 3 Panel Master PL035 7.2" displays, used for monitoring the real time state of production at the stations.

* Single PC running Microsoft Windows XP

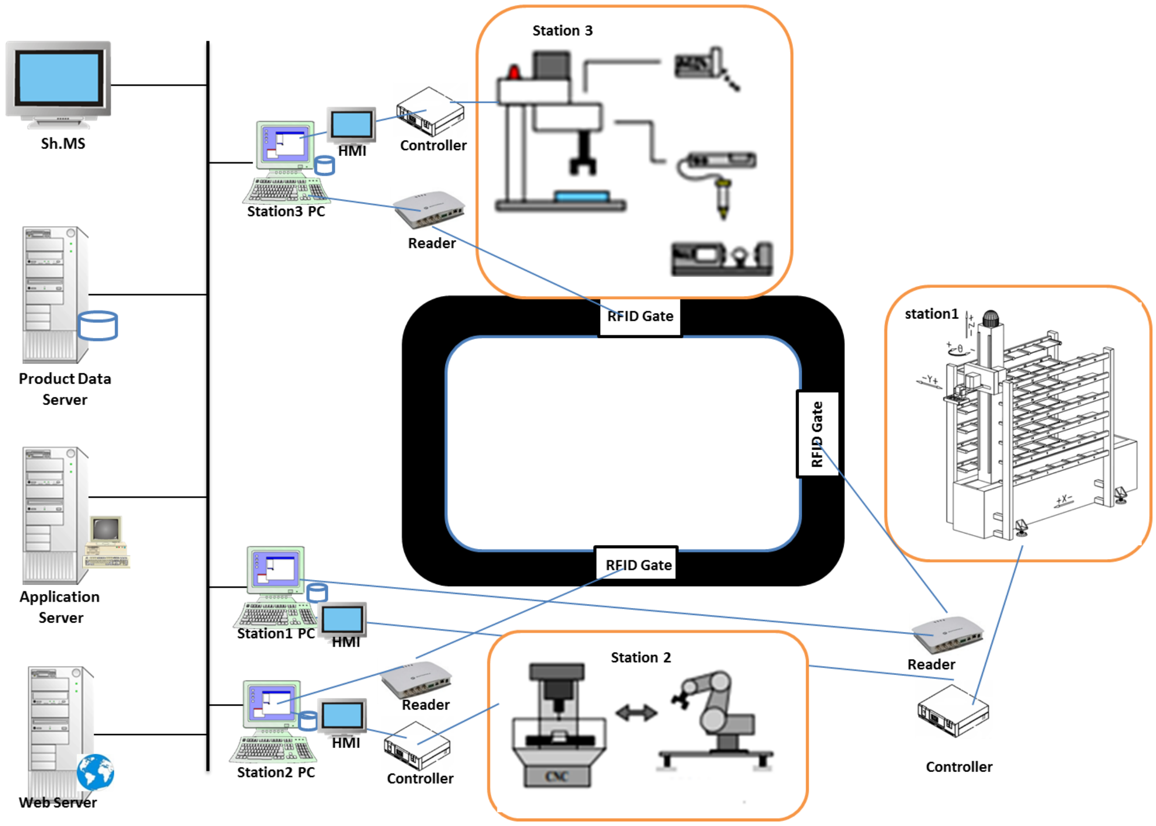


Figure 44- Hardware configuration

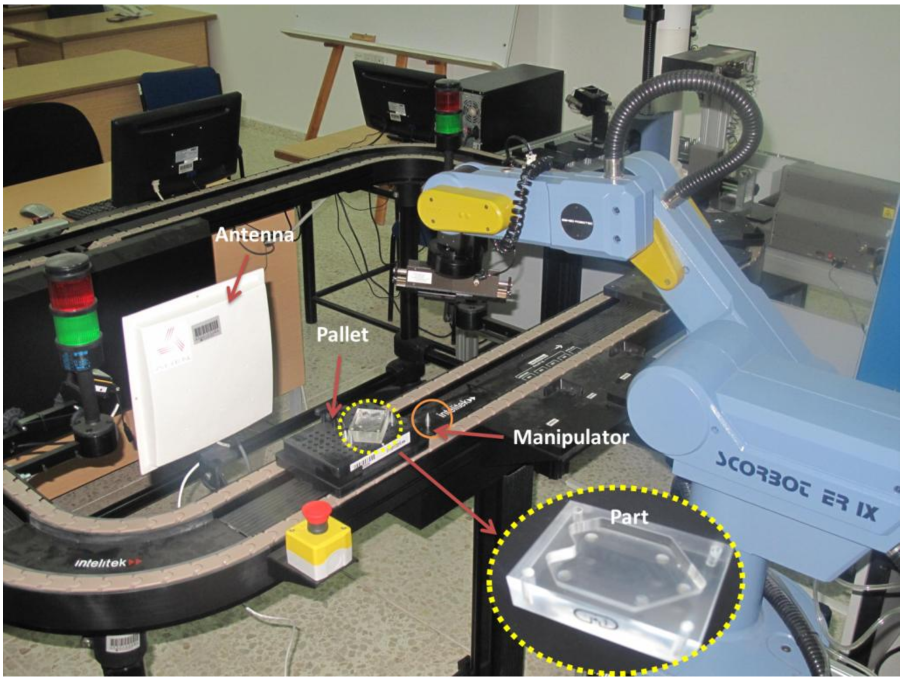


Figure 45- Machining Station RFID-gate

6.9.6 Agents and engineering tools

The MAS for our RFID-enabled IDCS was implemented using C# and the .Net framework. The .NET Framework is a runtime execution environment .NET applications. It consists of the common language runtime, which provides memory management and other system services, and an extensive class library offering robust, reliable functionality for all major areas of application development.

The Microsoft SQL Server database management system is used for development of the shop and stations databases. The C# source code for the reader was acquired at the manufacturer's website (http://www.motorolasolutions.com). All code for "Shop Management Agent", "Agent Manager", "Station Control Agent", and "Manufacturing Resource Agent" applications was written in C#, while that of the "Shop Monitoring and Command Agent" was developed in SWISH Max 4 software using the C programming language. The "Station monitoring Agent" and "Agent Machine Interface" were developed in PM Designer 2.0 and PM Designer V1.2, respectively, using the built-in Macro Language. Figure 51 depicts the dialog boxes in which a new product instances are shown for defining to the system.

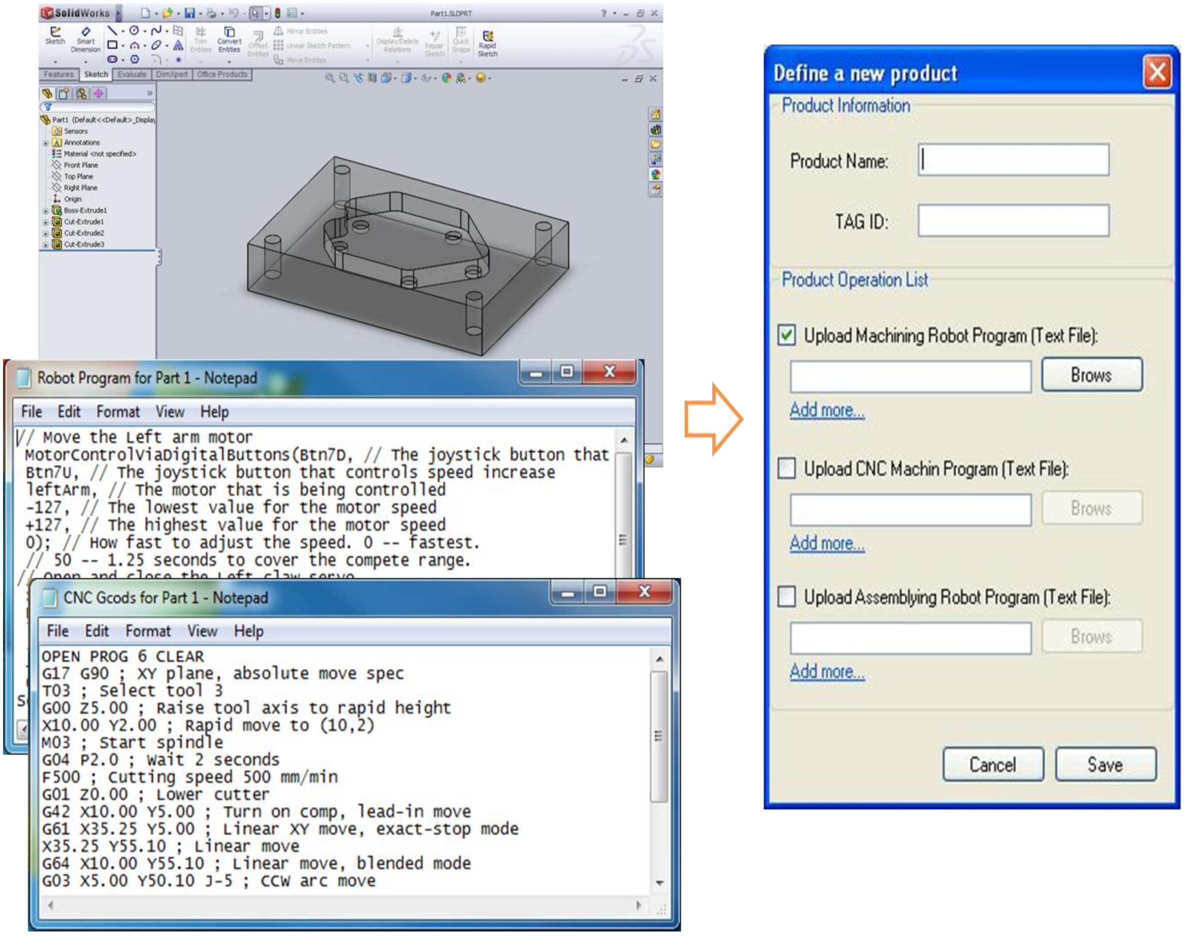


Figure 46- Defining a new product to the system

6.9.7 Interaction

Cooperation between all agents requires a robust interaction schema that supports information exchange, handles errors, and avoids deadlocks and other abnormal stoppage conditions. All agents developed in C# interact with Microsoft SQL Server (e.g., station database, Ontology, etc.) via the SQL DB Provider component, and with the “Shop Monitoring and Command Agent” via the Shell Shockwave ActiveX component. For the connection between the "Station Control Agent" and HMI using the RS232 port, the System IO Ports component was used.

The UML sequence diagram in Figure 52 illustrates the Robot control agent interactions with other agents. Figure 53 illustrates the shop monitoring system.

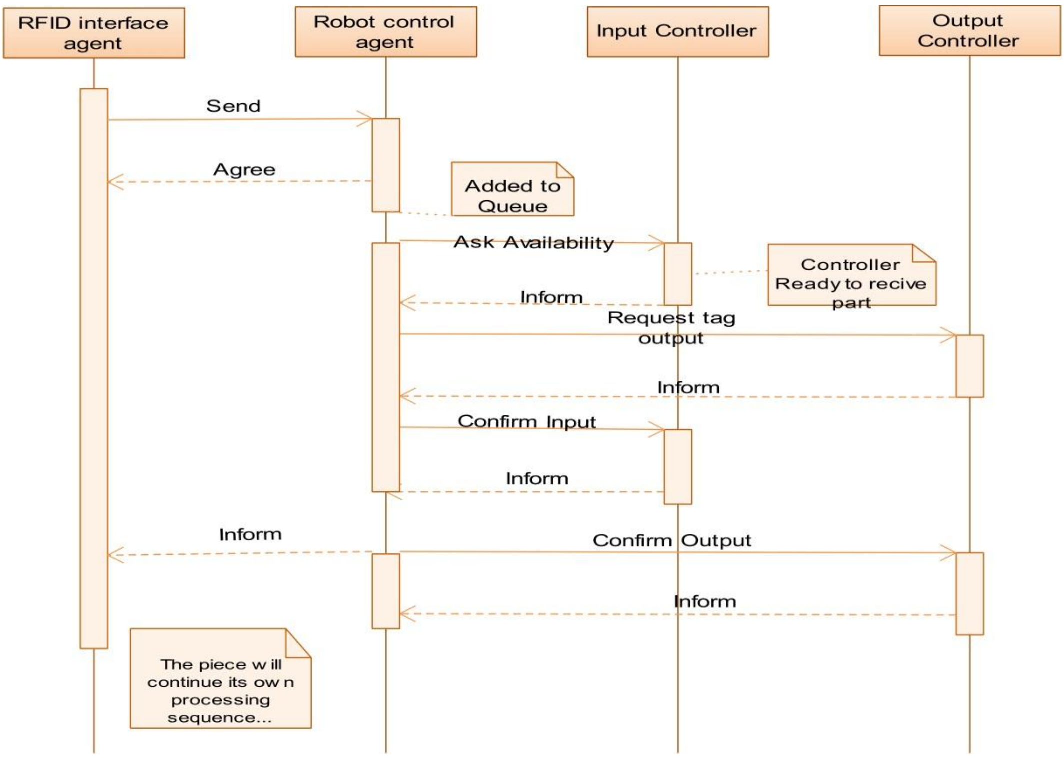


Figure 47- Interaction of the Robot Control Agent

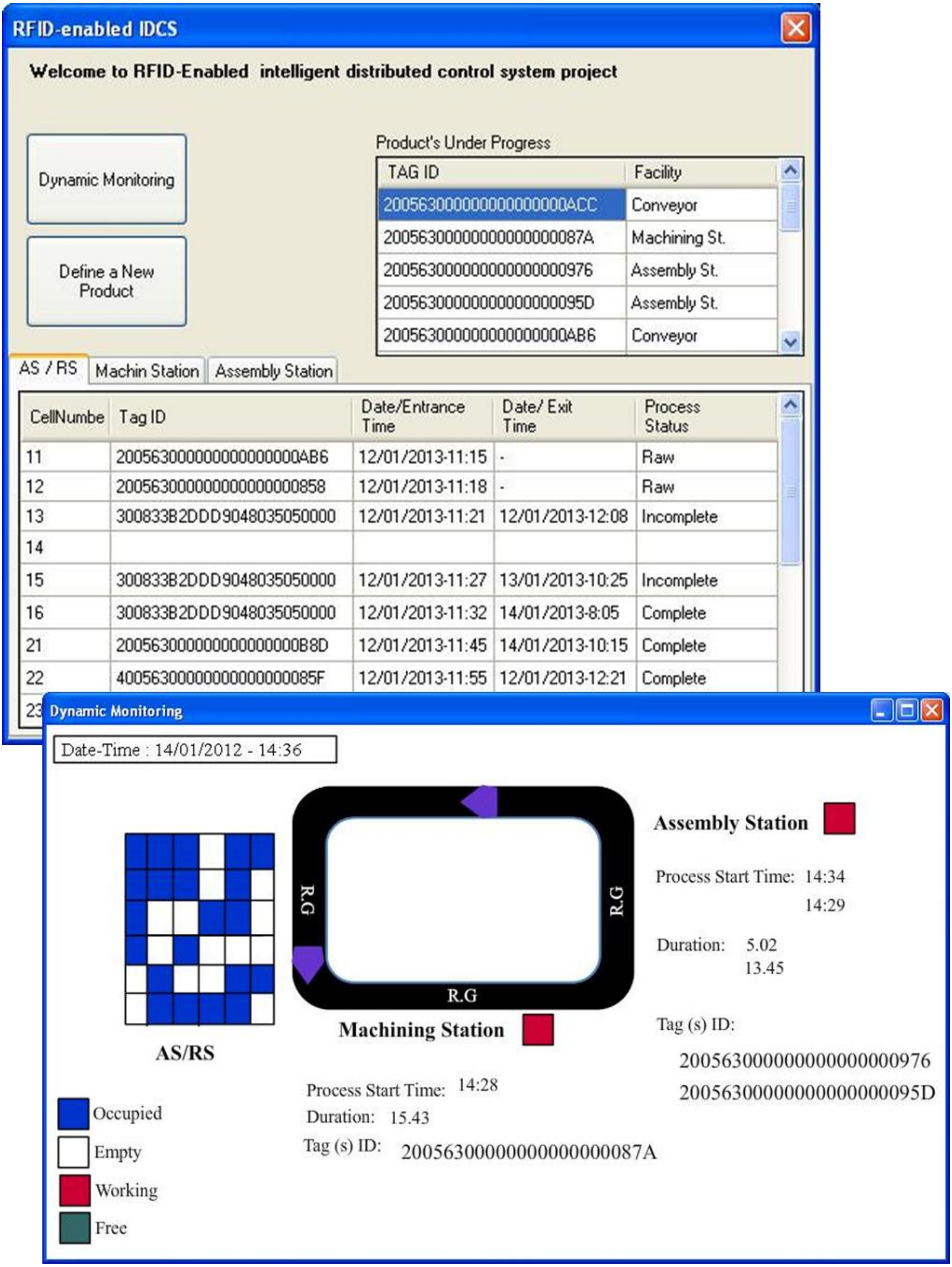


Figure 48- Shop monitoring system

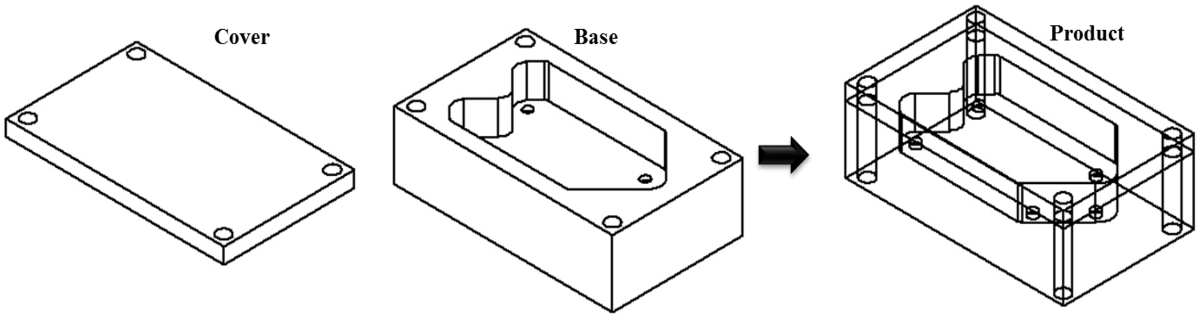
6.10 Experimental validation of RFID-enabled intelligent distributed control system

The validation of RFID-enabled IDCS requires their implementation in a real environment for analyzing their accuracy and applicability. This section describes the experimental validation of the proposed RFID-enabled IDCS at EMU's FMS laboratory. The obtained experimental results allow for the evaluation of the developed control system's performance.

6.10.1 Experimental procedure

The EMU's FMS laboratory was used as the test platform for experimentally evaluating the performance of the proposed RFID-enabled IDCS. In the test platform, several software agents were distributed at different IPC's, holds different platforms such as Windows XP and Windows2000. Distributed agents communicate amongst themselves over an Ethernet-based network. This demonstrates that the developed RFID-enabled IDCS supports heterogeneity. The performance and behavior of the developed RFID-enabled IDCS is compared with the performance of the conventional Centralized Control System (CCS). In the CCS (which is exist in the EMU FMS laboratory), Open-CIM software was used for the shop floor controlling and it is placed on a host computer. In RFID-enabled IDCS, the implemented prototypes multi-agent system were used, agents run on a completely decentralized control structure, whereas, the shop manager agent interacts directly for each (re-) scheduling decision. The barcode system is employed for part tracking in the conventional CCS; in contrast, active RFID tags in the new developed RFID-enabled IDCS are employed.

In this experiment, in order to produce desired product (contains two sub-products), ten operations must be realized on the Cover, Base as well as Product at the test platform, each operation having different processing times, as shown in Figure 54. The cutting operations can be performed on machine tending station without altering the operations sequence, whereas the non-cutting operations must be performed on the assembly and quality control station. For this experiment, it is considered that no setups are executed and that the conveyer performed the transport operations, the cumulative duration of which is 12 s. The sub-products are loaded sequentially from the AS/RS to the conveyer.



Part type	Operation No.	Batch size (second)	Unit processing time (second)	Station Name a: Assembly and quality control station b:Machine tending stations
Cover	Drilling	23	36	B
Cover	QC	16	24	A
Base	Drilling	25	36	B
Base	Drilling	23	35	B
Base	Milling	61	76	B
Base	QC	12	20	A
Product	Ball adding	10	12	A
Product	Gluing	15	24	A
Product	Assembly	25	32	A
Product	QC	10	18	A

Figure 49- Process Plans for the available products in the manufacturing shop

CCS and RFID-enabled IDCS were tested under two different plant scenarios. In the first plant scenario, there are no unexpected disturbances, where 100 products are ordered for production in the system. In the second plant scenario, the order of the products is changed from 100 to 50 at different working time (i.e.

working hour). For validation purpose, the RFID-based IDCS was evaluated and compared with CCS by analyzing the Average Lead Time, Average Throughput Tate, and Average Repeatability for both scenarios. The Average Lead Time is equal to the mean value of the manufacturing lead time for all the products at the desired experience. For a product, the manufacturing lead time is the total time required to process a given product through the factory plant, and comprises the setup time, the no-operation time, the idle time and the processing time. The Average Throughput Rate is the mean value of the throughput rates for all the products at the desired period of experience. For a product, the throughput rate was measured as the ratio between the number of parts produced in the experience and the batch time. The Average Repeatability is equal to the mean value of the percentage of utilization of all resources in the system.

6.10.2 Results and discussions

The experience gained during prototype implementation, debugging, and testing allows us to draw some conclusions about the operation of the RFID-enabled IDCS. It was verified that the system works as specified in both normal operation and in the presence of disturbances, thus validating the robustness of the developed system. Additionally, the re-configurability of the developed system was proven from its accurate reactions to the introduction, removal, and modification of manufacturing components. Specially, it was shown that when a “resource control agent” breaks down or leaves the system, other agents continue to find alternative solutions for executing the production plan.

6.10.3 Stable Scenario

In the scenario without the presence of unexpected disturbances, the system operates predictably. The results of this experimental test are summarized in Figure 55. In the stable scenario, the RFID-enabled IDCS present smaller values of manufacturing lead time (380) and higher values of throughput (51.2) than the CCS (respectively, 395 and 47.2). The better performance of that system is a result of cooperation by autonomous entities, i.e. agent manger that elaborates optimized production plans.

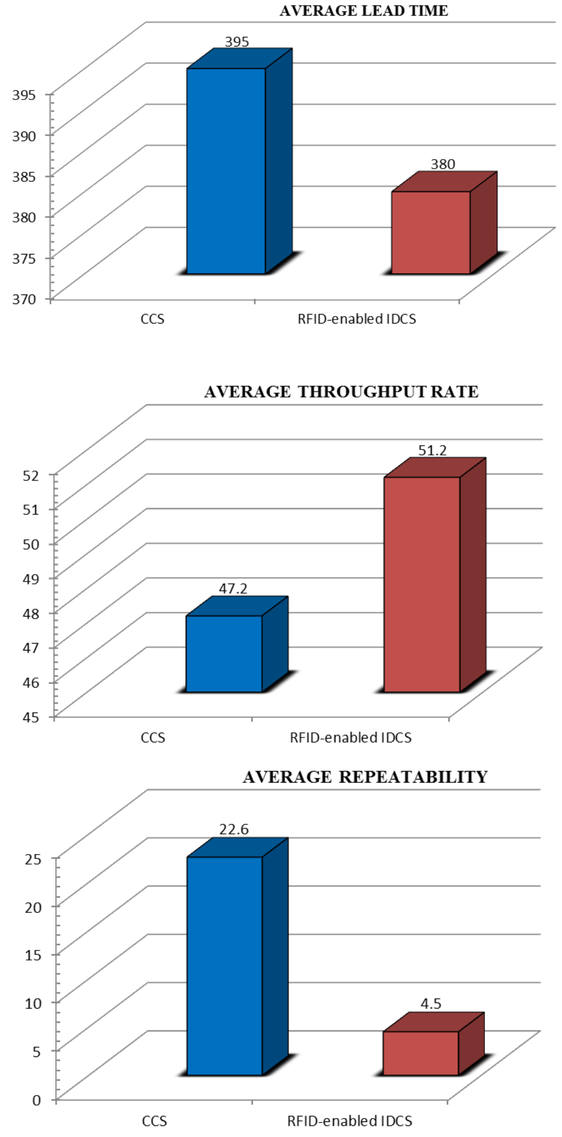


Figure 50- Performance of evaluated control approaches for scenario with no disturbance

An analysis of the repeatability of production planning, which is a measure of its predictability, clarifies that the repeatability values of the RFID–enabled IDCS is better than that of the CCS. In fact, in the RFID–enabled IDCS, the global schedule is achieved by interactions among operational controllers, which have a partial view of the entire system, which speeds up global optimization.

6.10.4 Disturbance Scenarios

The second experimental test considers the occurrence of unexpected business disturbances where, the order of the products is changed from 100 to 50 at different working time (i.e. working hours). The results of this experimental test are summarized in Figure 56.

The first conclusion extracted from these experimental results is the degradation of all performance indicators in the presence of disturbances at all the working time. From an analysis of lead time and throughput, it can be verifies that RFID-based IDCS offer better performance than the CCS respectively. For the desired product, the experiments shows that, CCS can accept order changes before the working hour starts to work, and thereafter, they produce the initially planned number of products because these schemes can never stop due to the synchronous nature. On the other hand, the RFID-enabled IDCS can still accept order changes up until the end of working hours. Thus, the developed RFID-enabled IDCS presents promising performance results because it shows better response to the disturbance scenario as evident from the smaller manufacturing lead time value and higher throughput value than the CCS. Also, the occurrence of disturbances increases repeatability of the control systems. It was verified that in disturbance scenarios at working time, the repeatability value of the RFID-based IDCS is very better than CCS (i.e. between 44.9 to 94.4).

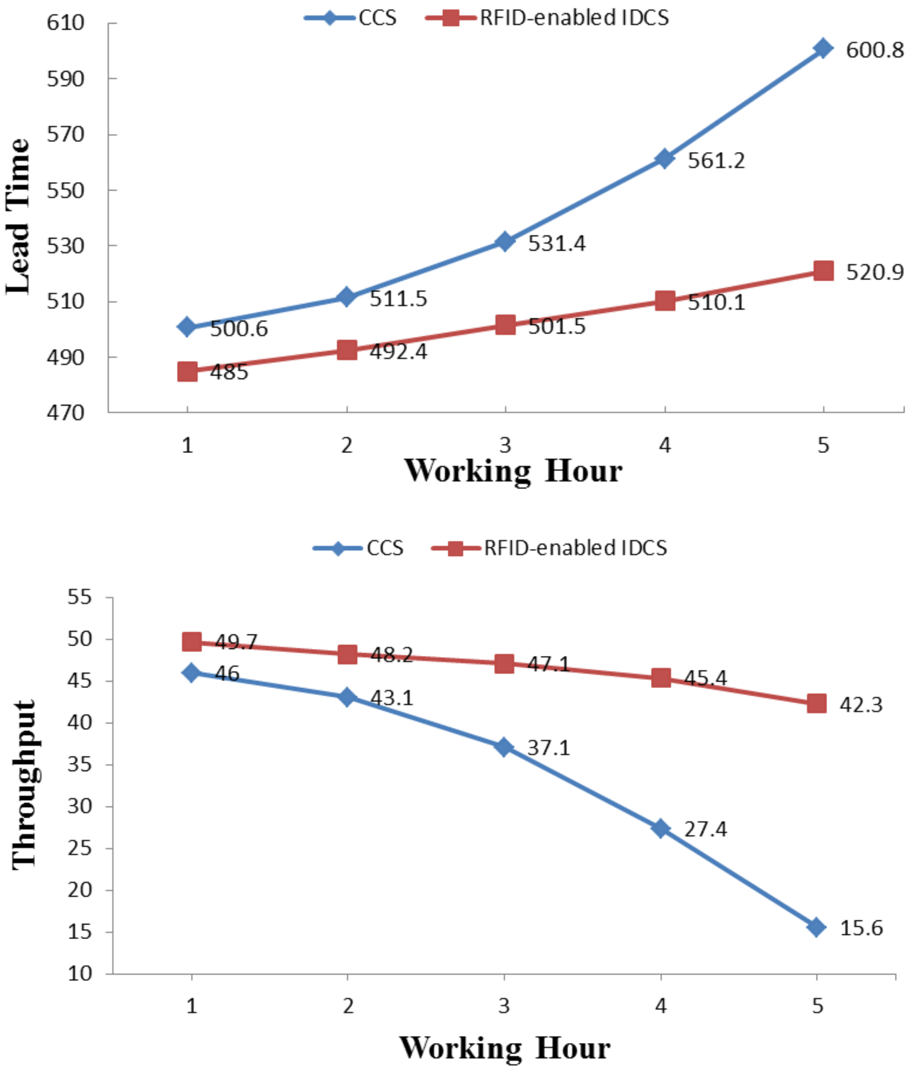


Figure 51- Performance of evaluated control approaches for disturbance scenarios

The second plant scenario was applied at five different working time of the system in order to comparing the responses of the control approaches to the different levels of entropy due to the occurrence of disturbances. However, it is possible to verify that the performance difference between the RFID-based DCS and CCS has been increased significantly when the disturbance applied at the in high working time (e.g.

at fifth working time, reduction of 15.3% in lead time and 63.1% in throughput). The experimental results confirm the observations made in the previous experimental test, thus clarifying that the performance of each control approach suffers with an increase in the entropy associated with the disturbance model. As expected, it is possible to verify that the RFID-enabled IDCS yields better values than the CCS. Given that agility is inversely proportional to the loss of productivity, the experimental results show that in both scenarios the RFID-enabled IDCS is more agile than the CCS. In scenarios where disturbances are more frequent, the levels of agility presented by all of the tested control approaches are reduced.

Chapter 7

CONCLUSIONS AND FUTURE WORKS

Conclusion from chapter 3

Establishment of a comprehensive modeling framework for organizational competency is a very important basis for the explanation of a generic competency modeling approach, a base element in the consolidation of existing knowledge in this area, tool for model developers for selecting appropriate competency models and a basis for its consistent further progress. In this way, as a contribution, a modeling framework for organizational competency considering multiple dimensions is proposed. The necessity and detail elements of each of the three dimensions on the proposed modeling framework, i.e. competency inherent characteristic, modeling perspective, and modeling intents are addressed. Finally, to benefit from the knowledge generated by other related research in this area, the most relevant other well-known competency models aspects and domains are evaluated with the three dimensions of the proposed modeling framework.

Conclusion from chapter 4

In this paper a capability-based data storage system for a manufacturing shop is structurally modelled using a case study of Computer Integrated Manufacturing (CIM) laboratory of Eastern Mediterranean University (EMU CIM lab). The research methodology of this contribution is divided into three phases, namely; “Preliminary study, problem definition phase”, “Design and development phase”, lastly “implementation phase”. An Object-oriented analysis approach is used as the modelling approach with the Unified Modelling Language (UML) employed as modelling languages. At the “Preliminary study, problem definition phase” the existing resources and realizable processes of the shop are explained for visualization of the shop. At the “Design and development phase”, UML use case and class diagrams of the “AS-IS” model of the shop are developed. For modelling the manufacturing process UML object and activity diagrams are used. Using UML object component and deployment diagrams the manufacturing resources of the shop are modelled. Three types of knowledge that exist in a manufacturing shop are modelled using UML class diagrams. At the “implementation phase”, the logical UML models are transferred in to a physical data base system. The Capability Analysis Tool (CAT) is developed as decision support systems for resource allocation and process as well as knowledge selection on a new business opportunity of the manufacturing shop. An experimental system has been implemented using the object-oriented database Object Store© and the Visual C++ programming environment. The developed experimental system offers four benefits, in that they a) enhance the organizations willingness to collaborate, b) boost the organization’s competitiveness, c) facilitate appropriate decision-making, and d) finally help to integrate the entire organization.

Conclusions from chapter 5

The paper first presents an overview of work in the area of enterprise’s competency modelling from two different perspectives, namely “managerial science and industrial engineering” and “IT managerial science”. The need for an empirical competency modelling from IT managerial perspective is discussed in detail, and the shortcoming of the existing competency models is discussed. An enterprise data infrastructure for integrating knowledge of the enterprise is presented and the responsibility of the competency model at intra-enterprise data infrastructure is highlighted. A Multi-level competency modelling framework for intra-enterprise is presented. The need for a multi-level modelling framework for cross functional co-ordination and integration for sector's capabilities is discussed in detail and the resulting requirements are represented. Based on previous contributions for capability modelling a generic sector capability model is proposed, and cross-functional co-ordination and cross-functional integration of the capabilities are defied as major advancements for intra-enterprise competency modelling. An example based on the proposed framework is presently under implementation. The developed experimental system offers four benefits, in that they a) enhance the organizations willingness to collaborate, b) boost the organization's competitiveness, c) facilitate appropriate decision-making, and d) finally help to integrate the entire organization.

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